NATIONAL
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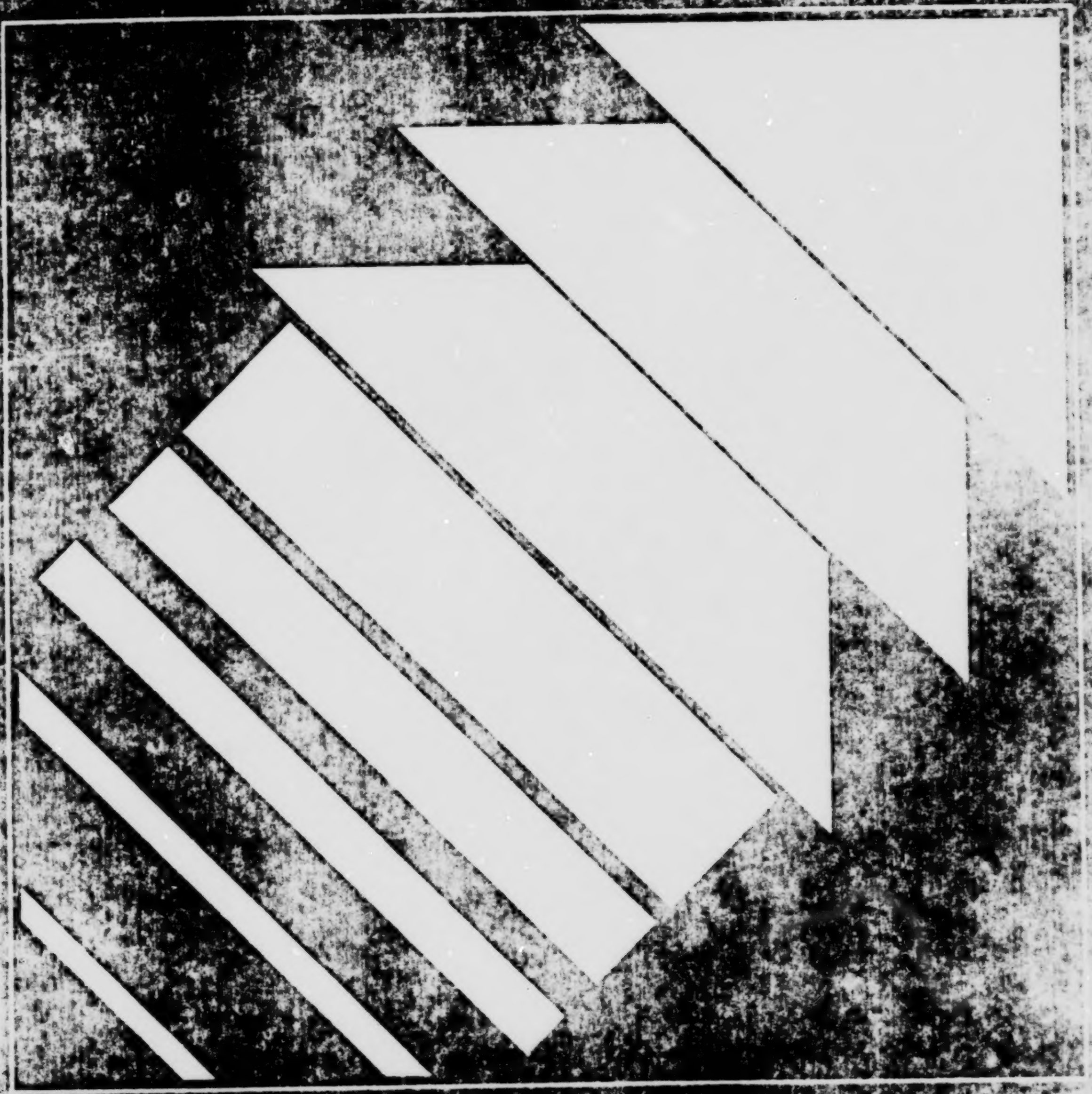
TAILINGS
PROGRAM

STUDY OF
ACID WASTE ROCK MANAGEMENT
AT CANADIAN BASE METAL MINES



Energy, Mines and
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Canada

STUDY OF
ACID WASTE ROCK MANAGEMENT
AT CANADIAN BASE METAL MINES

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June 17, 1987
Our File No. H86561

Mr. Roy John
CANMET
Energy, Mines & Resources Canada
555 Booth Street
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Dear Mr. John:

RE: DSS Contract No. 23317-6-1738/01-SQ

We are pleased to submit six (6) copies of our final report entitled, "Study of Acid Waste Rock Management at Canadian Base Metal Mines," in accordance with the above DSS contract.

We have very much appreciated the friendly cooperation of many industry, federal, and provincial officals in the course of conducting the study. We trust the report will serve the objective of helping to integrate acid waste rock into the RATS Program of applied research and will be pleased to offer any further assistance you may require in this regard.

Yours very truly,

NOLAN, DAVIS & ASSOCIATES
(N.S.) LIMITED

Alan V. Bell, P.Eng.
Principal

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EXECUTIVE SUMMARY

including Principal Findings and Conclusions

Approximately 315 million tonnes of acid waste rock (AWR) has been identified at 56 base metal mining properties in Canada. Of this total, 250 million tonnes occurs in British Columbia, 10 million tonnes in the Yukon, 50 million tonnes in Ontario, and 4 million tonnes in New Brunswick. Manitoba, Quebec, Newfoundland and the Northwest Territories have relatively minor quantities of acid waste rock associated with base metal mining.

Acid waste rock management is regarded as an important environmental issue in British Columbia and New Brunswick. In the other regions mentioned, reactive acid tailings are regarded as a more important issue related to base metal mining.

The technology to collect and treat contaminated leachate from AWR piles is well established and off-site contamination is a problem only at abandoned properties where these practices are not maintained (10 of the 56 properties identified). However, the application and systematic monitoring of preventative management methods for AWR are in their infancy both in Canada and elsewhere. There is, in fact, no proven method of AWR management for which backup leachate collection and treatment is not required in most circumstances, with the possible exception of underwater disposal. The effectiveness of passive treatment systems to handle residual leachate flows is also unproven under Canadian conditions.

Despite these shortcomings, the knowledge does currently exist to site and design AWR dumps so as to minimize the generation of contaminated leachates. There is evidence that well-constructed covers and seals can be effective in this regard although some ongoing maintenance will likely be required in most circumstances. The use of sealed waste dumps constructed on a cellular basis appears to have promise but has yet to be applied and monitored on a full-scale or pilot application. Underwater disposal, either in natural waters or in man-made systems also appears to be technically attractive and should be further evaluated as a priority item.

The ability to predict the extent and form of acid generation is important to the selection and design of AWR management systems as well as to the assessment of long-term mining operational costs. A significant refinement of currently available predictive techniques is required in this regard.

A program of AWR-related research is recommended for integration into the ongoing Reactive Acid Tailings Program. This involves the following:

1. Endorsement and integration into the RATS Program reporting and review system of 12 ongoing or proposed programs as identified in Table 5-2.
2. Coordination of AWR research needs with those relating to reactive tailings in each of the following areas:
    - Acid Generation Mechanisms in AWR
    - Predictive Techniques
    - Underwater Disposal
    - Sealing Techniques
    - Other Management Measures
    - Planning
3. Funding and implementation of seven new projects addressing the following topics as described in Section 5.3.1:
    - In-situ neutralization
    - Man-made wet disposal systems
    - Mine backfill criteria
    - Cellular dump construction
    - Groundwater implications of AWR dumps
    - Planning case studies
    - Institutional controls

The total cost of these programs is estimated to be in the order of $465,000 assuming that construction costs are adsorbed as operational expenditures at participating mines. This represents the value of projects which will require direct funding from the RATS Program and is incremental to the benefits that will be derived from other related projects included in Item 1.

PART 1

1.0 INTRODUCTION

The Reactive Acid Tailings (RATS) Program was initiated in 1983 in response to the recognition by the base metal mining industry and government that the long-term management of acid generating wastes constitutes a serious problem with respect to the abandonment of mining properties in a manner that is both environmentally and economically acceptable.

The Program management structure is comprised of a Steering Committee, consisting of five senior industry and government representatives, which has overall responsibility for the Program, plus a Technical Working Group with representatives drawn from industry and provincial and federal agencies. The function of the Technical Working Group is to advise and assist the Steering Committee in the technical management of the Program as well as to provide a forum for representation by a wide range of industry, regional, and scientific interests. A senior member of CANMET staff acts as secretary to both committees.

The first industry/government contracts were let in the summer of 1985 with an overall schedule of 5 years set for the Program. This has since been extended to a 1992 completion target.

During the fall of 1986, the Steering Committee decided to broaden the scope of the Program to include reactive waste rock at base metal mines. An acid waste rock (AWR) subcommittee of the Technical Working Group was formed and met for the first time on January 14, 1987. Prior to this meeting, CANMET (via the Department of Supply and Services) contracted with Nolan, Davis & Associates to prepare this report, which is designed to assist the AWR Subcommittee in formulating an appropriate program of work to address the issue of acid waste rock management at Canadian base metal mines.

The report has been prepared with the benefit of inputs from a majority of Technical Working Group members as well as from other senior industry and government representatives in each province having acid waste rock associated with base metal mining. The report provides an inventory of AWR in Canada; defines the status of research and development into AWR in Canada and elsewhere; reviews alternative AWR management methods; and presents a recommended program of research and development.

PART 2

2.0 ACID WASTE ROCK IN CANADA

2.1 Location and Extent

2.1.1 Approach

An important objective of the study is to develop an inventory of acid waste rock situations at Canadian base metal mines. Secondary requirements include developing an appreciation of the level of data pertaining to acid waste rock and the degree of importance with which the issue is regarded, relative to other environmental matters in each province.

These objectives were addressed through a series of meetings with industry and government representatives, held in the capital of each province in which there was thought to be an acid waste rock problem. Such meetings were held in Victoria, Winnipeg, Toronto, Quebec, and Fredericton. Subsequent review meetings were held in Ottawa with CANMET and Environment Canada personnel and in Bathurst, New Brunswick, with members of the RATS Technical Working Group. Minutes for each meeting are included in Appendix One. The situation in Newfoundland and in the Territories was assessed through direct discussions with regulatory personnel.

Data obtained on the extent of Acid Waste Rock at Canadian based metal mines, are summarized in Table 2-1 and the current status of waste rock management in each province is reviewed in the following sections.

2.1.2 Review by Province

BRITISH COLUMBIA

Five operating and four abandoned base metal properties in British Columbia were identified as having acid waste rock (ref. Table 2-1). Acid waste rock management is regarded as an extremely important environmental issue in British Columbia due to the size of most of the operating mines; the sensitivity of the receiving environment (particularly with respect to salmonid resources), and the potential for future mining development in areas likely to result in reactive wastes.

The four operating open pit mines in British Columbia having acid waste rock; namely, Gibraltar, Equity Silver, Noranda Bell, and Westmin account for approximately 250 million tonnes of acid waste rock in place. At current rates of production, the first three of these properties account for an accumulation of about 25 million tonnes per year of reactive rock

TABLE 2-1

KNOWN REACTIVE WASTE ROCK AT BASE METAL MINES IN CANADA

Province/Property	Metals Mined	UG or OP	Currently Active ?	Tonnage of Reactive Waste Rock	Comments
British Columbia					
Gibraltar	Cu	OP	Yes	91 x 10^6	Concern over bioleaching of waste piles.
Equity Silver	Cu, Ag, Au	OP	Yes	70 x 10^6	Waste pile temperatures of 55 degrees Celsius recorded.
Westmin	Cu, Zn	OP & UG	Yes	8 x 10^6	Several different AWR management strategies considered.
Noranda Bell	Cu	OP	Yes	60 x 10^6	Operation will close in 2-3 years.
Sullivan	Zn, Pb	UG	Yes	Minor	Tailings primary issue.
Brittania	Cu	UG & GH	No	Minor	AMD primary concern.
Anyox	Cu	UG	No	See next column	No waste piles but AWR in rail bed.
Mount Washington	Cu	OP	No	0.4 x 10^6	Cover & other measures being considered.
Tulsequah	Cu,Pb,Zn,Au	UG	No	Minor	AMD primary concern.
Alberta					
No base metal mines.					
Saskatchewan					
No base metal mines.					
Manitoba					
Flin Flon	Cu, Zn	OP & UG	Yes	See next column	No current evidence of acid generation.
Rattan	Cu, Zn	OP & UG	Yes	Not known	Acid but drains into tailings pond.
Dickson	Cu, Zn	UG	No	Minor	
Pipe	Ni	OP & UG	Yes	See next column	WR appears to be acid consuming.
Thompson	Ni	OP	Yes	See next column	WR appears to be acid consuming.
Maskwa	Ni, Cu	OP	No	See next column	Thought to be little sulphide in WR.
Dun Barton	Ni, Cu	UG	No	Minor	Thought to be little sulphide in WR.
Manibridge	Ni, Cu	UG	No	Minor	Thought to be little sulphide in WR.
Don-Jon	Cu, Zn	UG	No	Minor	Acid but only small volume.
Ontario					
Kidd Creek	Ni, Cu	OP & UG	Yes	Not known	WR is low grade ore, being milled.
Frood Stobie	Ni, Cu	OP & UG	yes	8 x 10^6	Many AWR piles, leachate collected and treated.
Murray-Clarabelle	Ni, Cu	UG	Yes	12 x 10^6	Many AWR piles, leachate collected and treated.
Creighton	Ni, Cu	OP & UG	Yes	Not known	Many AWR piles, leachate collected and treated.
Garson	Ni, Cu	UG	Yes	1 x 10^6	Tailings primary issue.
Levack	Ni, Cu	UG	Yes	1 x 10^6	Development rock used for constn.
Strathcona Creek	Ni, Cu	UG	Yes	10 x 10^6	Widely dispersed. Used for constn.
Fraser	Ni, Cu	UG	Yes	3 x 10^6	12 ha wastepile & mine yard.
Fecunis	Ni, Cu	UG	Yes	See next column	Tonnage included in Strathcona area.
Onapine-Craig	Ni, Cu	UG	Yes	0.7 x 10^6	AWR used in roads, etc.
Sherman	Fe	OP	Yes	1.9 x 10^6	AWR very reactive.
Mattabi	Cu,Zn,Pb,Ag	OP & UG	Yes	+1.7 x 10^6	Overburden, gossan, & waste coffer piles (3).
Lyon Lake	Cu,Zn,Pb,Ag	UG	Yes	Minor	AMD primary concern.
F. Group	Cu, Zn, Ag	OP	No	Minor	Leachate treated in open pit.
Geco	Cu, Zn, Ag	OP & UG	Yes	Not known	AWR used extensively for constn.
Kam Kotia	Cu, Zn	OP & UG	No	0.2 x 10^6	Tailings primary concern. Controlled by Crown.
Other	Varies	Varies	No	Not known	Estimated approximately 200 abandoned sites in province, many with associated AWR problems.
Quebec					
Gaspe	Cu	OP & UG	Yes	Minor	AWR is actually leach opn. residue.
Weedon	Cu, Zn	Op	No	Not known	AWR used extensively for constn.
Solbec Cupra	Cu, Zn	UG	No	30,000	Sulphide waste pile covered in 1979.
Doyon	Au	OP	Yes	Ref. note a	Took several years to go acid.
East Sullivan	Zn,Pb,Cu,Ag	OP	No	Not known	120 acres mixed tailings & AWR.
Manitou-Barvue	Zn, Pb, Cu, Au, Ag	OP & UG	Yes (mill only)	Not known	AWR used extensively for constn.
Poirier	Cu, Zn	UG	No	Not known	AWR used extensively for constn.
Lac Watson	Cu, Zn, Ag	UG	Yes	Not known	Tailings primary concern.
Normetal	Cu,Zn,Ag,Au	UG	No	Not known	Tailings primary concern.
New Brunswick					
Brunswick No. 6	Pb, Zn, Cu	OP	No*	+3 x 10^6	Four AWR piles, reclamation in progress.
Heath Steele	Pb, Zn, Cu	OP & UG	No*	~1 x 10^6	20+ AWR piles.
Caribou, NB	Pb, Zn, Cu	OP & UG	No*	Not known	Majority of AWR moved to pit.
Key Anacon	Pb, Zn	UG	No	Not known	Small AWR pile.
Wedge	Cu	OP	No	N/A	Site reclaimed.
Northumberland	Pb,Zn,Au,Ag	OP	Proposed	N/A	Removal of gossan and leaching proposed.
Nova Scotia					
No base metal mines with AWR.					
Prince Edward Island					
No base metal mines.					
Newfoundland and Labrador					
Rambler	Cu	UG	No	Minor	AWR not considered an issue.
Buchans	Cu, Pb, Zn	UG & GH	No	Minor	AWR not considered an issue.
Whales Back	Cu	UG	No	Minor	AWR not considered an issue.
Gullsbridge	Cu	UG	No	Minor	AWR not considered an issue.
Yukon					
Curraugh Resources	Pb, Zn	OP	Yes	10 x 10^6	[b]Focus primarily on tailings to date.
United Keno Hill	Ag, Pb, Zn	UG	Yes	Minor	AMD primary concern.
Northwest Territories					
Nanisivik	Pb, Zn	UG	Yes	Not known	Acid development rock on site.

AWR:	Acid Waste Rock
WR :	Waste Rock
OP :	Open Pit Mine
UG :	Underground Mine
GH :	Glory Hole

*Acid drainage treatment maintained.

[a] Total volume approx. 30 x 10^6 tonnes but not included in inventory total due to not being a base metal property.

[b] Total volume of WR is 200 x 10^6 tonnes but only 5% is acid producing.

potentially requiring leachate control and treatment. The Westmin Mine is now an underground operation.

Each of the operating mines in British Columbia collects and treats contaminated leachates from their respective waste rock storage areas and the current impact of the material on the aquatic environment is, therefore, well controlled. There is, however, a concern, on the part of both industry and government, over the long-term costs of maintaining post-production controls at these and any future properties. This concern has lead to the recent establishment of a provincial task force to address the issue of acid waste rock management in British Columbia.

Of the four non-operational mines identified in Table 2-1, the Mount Washington property is having the greatest impact that can be directly associated with acid waste rock disposal. There are currently no preventative or control measures in place and during periods of high runoff, particularly during the snow melt, high levels of contamination are flushed into the receiving environment. The property is controlled by the Crown and studies are currently being undertaken to determine the most cost effective ways of dealing with the situation over the long-term.

At the time of writing, approximately ten gold mining properties were in the application review process in British Columbia and many of these properties are reported to have acid generation potential (Ferguson, 1987a)

The characteristics of the nine base metal properties listed in Table 2-1 are described in the provincial meeting notes in Appendix One. There are, however, a number of features pertaining to some of these properties which should be reviewed relative to future research and monitoring. These include the following:

1. **Gibraltar Mine:** The waste rock from this large open pit copper mine was initially regarded as acid consuming but, five to six years ago, elevated sulphate levels were observed from one of the waste dumps. In 1986, the company put into operation an acid bioleach system on the No. 3 dump with a view to leaching its copper values. It is hoped that this will remove the sulphides within the waste but there is concern that alkalinity will also be removed and that the entire dump will

become a long-term acid producer. Plans are currently being formulated to leach a second of the three dumps at the property.

Long-term observation of this dump-leaching operation will provide considerable insight into the effectiveness/implications of attempting to speed natural leaching processes, with a view to ultimately achieving a stable system.

2. **Equity Silver:** Prior to production, which commenced in 1980, it was predicted that acid generation at this large open pit operation would not occur due to unfavorable climatic conditions. However, the waste rock has proven to be extremely reactive and the control of contaminated leachates from the large side-hill waste dump is now a major operational consideration. Temperature probes positioned in the dump are recording temperatures in the order of 55° C. A 1 metre thick till cover has been placed on the side slopes to reduce air infiltration but, as yet, the temperature within the dump has barely responded to these measures.

   Placement of waste rock in a flooded open pit has been successful in preventing acid generation although zinc levels are slightly above permitted values. A number of waste rock test plots have been established at the site, with a view to checking the effectiveness of different cover techniques.

3. **Westmin:** This operation has experimented with the injection of AMD treatment sludge and tailings into their waste rock piles with a view to reducing the voids ratio. These experiments were not successful due to difficulty in retaining the material within the interstices of the dump. Column tests of sludge injection into waste rock, conducted at Equity Silver, showed positive results until the alkalinity in the sludge was depleted, afterwhich the acid production potential of the column became far worse than the presludge injection condition.

   The long-term management plan for this property calls for extending the tailings deposition back over the waste rock disposal area such that it will be partially covered by layered tailings. This will constitute a unique management technique, both in terms of the long-term behavior of the waste rock and of the layered tailings.

Overview of Applied Research Opportunities in British Columbia

Ongoing or proposed work at the Gibraltar, Equity Silver, Westmin, and Mount Washington properties in British Columbia, will provide valuable inputs to the development of acid waste rock management techniques for the Canadian mining industry. Also of interest is the fact that sulphide tailings have been deposited in natural lakes or coastal waters at five properties in British Columbia. A continuation of recent research on the quality of interstitial water associated with the underwater disposal of sulphide materials, will have valuable implications relative to acid waste rock disposal as well as to tailings (ref. Section 4.3.1).

MANITOBA

A total of nine properties were identified as having potentially acid waste rock, although on detailed review, it appears that, in the majority of cases, the waste rock is either low in sulphides or acid consuming, despite the high sulphide contents associated with the ore bodies. Only the Rattan and Don-Jon mines are specifically known to have acid producing waste rock. In the former case, leachate drains into the tailings pond and is not regarded as a problem. The volume of acid waste rock at the Don-Jon property is reported to be very small, representing development rock from an underground sulphide operation at which only 87,000 tonnes of ore were mined.

Acid waste rock management is not regarded as a significant environmental issue in Manitoba, even within the context of the mining sector.

ONTARIO

Sixteen specific properties, representing a total volume of acid waste rock of approximately 50 million tonnes, were identified in Ontario. These are listed in Table 2-1. In addition to these properties, there is a large number of abandoned properties in the province, many of which result in acid contamination from uncontrolled tailings and waste rock leachates.

It is interesting to note on Table 2-1 that the majority of mines listed for Ontario are underground operations that are still active. This results in the volume of waste rock being relatively small as compared to open pit operations, as well as in relation to the volume of sulphide tailings generated at these operations. Since the majority of mines are still operational contaminated leachate can be collected and treated thus minimizing the external impact of these properties. For these reasons, the issue of acid waste rock management is not regarded as being a particularly high environmental priority by regulatory agencies in Ontario, particularly when compared to the management of uranium and reactive sulphide tailings.

Falconbridge Limited is undertaking a number of applied research programs with respect to acid generating tailings and waste rock at its Sudbury operations:

- At the Fecunis site, approximately 35 hectares of pyrrhotite tailings have been covered with a 1.3 m layer of waste rock. Approximately half of this area was then dosed with 1 tonne per acre of sewage sludge. Tensiometers have been installed and will be measured weekly for nickel, copper, iron, pH, and sulphates. This will provide an evaluation on the effects of sewage on waste rock and tailings.

  In addition to the sewage sludge experiments, test plots have been established to evaluate the effects of adding waste lime/limestone to the waste rock cover using a dose rate of 100 tonnes per hectare. Municipal garbage is also being used as an experimental waste rock and tailings ameliorant.

- At the Fraser Mine site, chemical treatment of waste rock is being evaluated. Actual treatments to be applied have yet to be decided but column experiments are being conducted on various dosages of lime/limestone mixtures, calcium phosphate monobasic, apatite and bactericides.

The Kam Kotia site is an abandoned property now controlled by the Crown. Bids are currently being evaluated by the Ontario Ministry of Natural Resources for the reclamation of the site. Although this will focus primarily on the large area of confined and unconfined tailings, a volume of approximately 200,000 tonnes of acid waste rock will also have to be dealt with. Monitoring of this reclamation process will therefore provide a valuable input to the understanding of sulphide materials management.

The Sherman Mine, an open pit silicate iron operation, produces a highly reactive waste rock. Different methods of reducing the volume and potency of leachate from its disposal areas are currently being evaluated.

QUEBEC

Acid waste rock is not regarded as a serious environmental issue at base metal mines in Quebec. A total of nine properties were identified in which acid waste rock is known to exist, including one gold mine (Doyon). This property has approximately 30 million tonnes of acid waste rock but has not been included in the study inventory as it would distort the figures for other provinces which address only base metal mines as defined in the Terms of Reference.

Only three of the properties listed are currently operating (Gaspe, Doyon, and Lac Watson). The acid generating material at Gaspe is a residue from a leach operation and is a relatively small tonnage. In many cases, the acid waste rock is closely associated with acid tailings disposal at the site and is therefore regarded as an integrated problem. Very little data exist relative to the tonnage or other characteristics of acid waste rock at the Quebec properties listed in Table 2-1.

Bactericides have been applied to small areas at the Doyon mine in an attempt to control acid generation and the operators propose to increase the scope of these applications in 1987.

A waste pile containing 30,000 tonnes of AWR at the Solbec-Cupra site was covered with 20 cm of soil in 1978-79. Some erosion of the side slopes has occurred.

The above two properties may provide some opportunity for evaluating AWR management measures in Quebec.

NEW BRUNSWICK

Acid waste rock is an important problem associated with the base metal mining operations in the high-sulphide mineralization of Northeastern New Brunswick. A total of six properties are identified in Table 2-1. Of these, Brunswick No. 6 and Heath Steele have the largest tonnages. Leachates from waste rock and other contaminated areas at these sites are controlled and treated prior to discharge.

Brunswick Mining and Smelting is currently undertaking a program of reclamation at its No. 6 property. This involves both the removal of high sulphide rock to the open pit and potential covering of remaining materials.

The Heath Steele site is currently closed, although the mine is being pumped and the drainage control and treatment system operated by Brunswick Mining. There are approximately 21 waste rock piles at the site and acid generating material has also been used for construction purposes in the area. Long-term management of this situation is a concern to both industry and regulators due to the cost involved and the fact that the site drainage ultimately discharges to the Northwest Miramichi, an important Atlantic salmon stream. Brunswick Mining have recently submitted a proposal for funding assistance under the Mineral Development Agreement for a waste rock reclamation research program at the site.

Acid mine drainage is treated at the Caribou NB site and it is currently hoped that the mine will be reopened by its new owners. Reclamation measures were successfully applied at the Wedge Mine in the Nepisiguit River Basin. These consisted of backfilling waste rock into a pit created by the collapse of the mine crown and sealing the surface with till.

Acid drainage is experienced at the surface coal mining operations of NB Coal near Minto but has not been included in the inventory due to the limitation of this study to base metal properties.

NOVA SCOTIA

The Rio Algom tin mine is the only active base metal property in Nova Scotia. It is an open pit operation with non-acid-producing wastes. There are at least two abandoned base metal properties in the Province (Gays River and the Stirling Mine), but these are also non-acid producing.

Sulphide oxidation is an issue in Nova Scotia, particularly in association with the Meguma slates in southern areas of mainland Nova Scotia, in which a number of potential gold operations are located and on which the Halifax Airport has been constructed. This has been reported by a number of authors; including, Smith, 1987; Lund, 1987; Hennigar, 1987; and Albright, 1987.

The majority of coal mined in Nova Scotia and particularly that of the Cape Breton Development Corporation mines in and around Sydney have sulphur levels ranging from 2 to 5 percent which results in acid generation being associated with process tailings and waste rock (Nolan, Davis & Associates, 1986).

NEWFOUNDLAND AND LABRADOR

Four base metal operations were identified in Newfoundland. These were all underground operations and are now closed. Acid waste rock is not regarded as a problem at any of these properties although the tailings associated with each are potentially acid generating.

The new Hope Brook gold property currently under development has potentially acid generating waste rock as well as ore to be heap leached. This mine has not been included in the inventory on Table 2-1.

YUKON

Two base metal properties in the Yukon have potential acid waste rock problems associated with them: the Curraugh Resoures mine near Faro is an open pit operation previously operated by Cyprus Anvil. Work carried out to date on the waste rock associated with the property indicates that approximately 95 percent of the rock is acid consuming but that the remaining 5 percent (approximately 10 million tonnes) is a sandy pyritic material which is highly acid producing. The tailings are also potentially acid producing and various schemes to manage the tailings have been considered. One such scheme involves the construction of a large dam in excess of 50 m in height to permanently flood the entire life production of mine tailings. However, agreement has recently been reached with the Yukon Water Board on conducting a series of trials designed to evaluate the way in which the long-term effects of permafrost on the tailings might be used to advantage. This latter approach may offer significant cost savings and will provide an opportunity to further research the properties of sulphide wastes under northern conditions.

The United Keno Hill property is an underground mine known to produce acid mine drainage. There is some mine development rock existing at the site but its volume and characteristics are not currently known.

NORTH WEST TERRITORIES

The Nanisivik property on Baffin Island is the only base metal property in the Northwest Territories known to have an acid waste rock problem. The mine expects to operate until about 1992 and has just started development of an abandonment plan which will address the long-term management of the waste rock. This should provide an opportunity to evaluate management measures under Arctic conditions.

2.2 Impact of Acid Waste Rock in Canada

The current distribution of acid waste rock at base metal mines in Canada is roughly as follows:

Province/Territory	tonnes
British Columbia	250,000,000
Alberta	None
Saskatchewan	None
Manitoba	probably less than 100,000
Ontario	50,000,000
Quebec	probably in the order of 250,000
New Brunswick	4,000,000
Nova Scotia	None
Prince Edward Island	None
Newfoundland & Labrador	Probably less than 100,000
Yukon	10,000,000
Northwest Territories	probably less than 500,000
Approximate Total:	315,000,000

It is important to appreciate that the above figures are only approximate and that they represent only base metal properties. Acid waste rock is also associated with a number of other minerals in Canada including gold, uranium, and coal which were not included in the Terms of Reference for this study.

The technology to control the impact of acid drainage from reactive waste rock is well established as long as the responsible party is able to bear the long-term cost of collection, treatment, and sludge disposal. Thus, the instances of actual contamination resulting from the disposal of acid waste rock are usually associated with abandoned properties that have reverted to the Crown, such as the Mount Washington property in British Columbia or the Kam Kotia site in Ontario. Elsewhere, some form of collection and treatment facilities are normally maintained by the owner/operator of the site.

Placing reliance on the operation of essentially mechanical systems for the long-term protection of environmental quality, particularly at remote sites, obviously involves a finite risk of failure, even assuming the operational costs can be accommodated by those concerned.

The need to find preventative methods of acid waste rock management, so as to remove or lessen the reliance on long-term control and treatment of resulting leachates, is most acutely felt in British Columbia and New Brunswick. The sensitivity towards acid waste rock management in these two provinces results from the fact that both regions support valuable salmon resources which are threatened by uncontrolled mining wastes; both have a number of existing sites at which the control of acid waste rock leachates is a significant issue, and both recognize that future mining development in their respective areas will lead to an increasing problem unless preventative measures are developed and applied.

Despite the fact that Ontario has the largest number of base metal mines with acid waste rock, the problem is regarded in the provincial perspective as being secondary to uranium and reactive acid tailings management. This perspective probably results from the fact that the majority of mines are underground operations and are thus currently producing relatively small volumes of reactive waste rock as compared to tailings, plus the fact that contaminated leachates from waste rock areas are reliably controlled and treated at the majority of the properties identified on Table 2-1.

The only other areas of Canada where acid waste rock is seen as being a significant environmental issue associated with base metal mining would be the Curraugh Resources property in the Yukon, where the concern centres more on long-term reactive tailings management, and at the Nanisivik property in the Northwest Territories, for which a closure plan must be developed prior to 1992.

2.3 Control/Preventative Measures at Canadian Mines

An analysis of the 56 mines identified in Table 2-1, indicates that there are 33 properties with potential contamination problems from acid waste rock leachate that currently apply some form of leachate control or treatment. The situation at the 56 sites can be summarized as follows:

- abandoned, no controls required	3
- abandoned, AWR contamination problem	10
- closed, controls maintained	5
- operational, AWR leachate controlled	28
- others	10
- TOTAL	56

In all cases where controls are applied, this takes the form either of directing contaminated AWR leachate to a tailings pond for combined treatment or applying conventional lime treatment to the segregated waste rock leachate.

Very few acid waste rock management measures other than leachate control and treatment have been attempted at Canadian base metal mines. Exceptions include the following:

- underwater disposal in abandoned pit - Equity Silver
- waste dump side-slope covers and horizontal seals - Equity Silver
- biocide applications - Equity Silver
- tailings and treatment sludge injection into waste dump - Westmin
- soil cover on waste pile - Solbec Cupra
- use as backfill in underground mine - Brunswick No. 6
- use as backfill in open pit - Brunswick No. 6
- processing for residual mineral values - Kid Creek
- backfilling into pit and surface seal - Wedge Mine

An important conclusion to be drawn from this experience is that nowhere in Canada have preventative measures been applied to either an active or abandoned acid waste rock storage facility and the results monitored over time. The situation at the Wedge Mine in New Brunswick was more a case of backfilling and hydraulically sealing a crown cave-in.

2.4 Opportunities for AWR Research at Canadian Mines

Based on the foregoing inventory, a number of opportunities for monitoring and applied research into acid waste rock management can be identified. These are summarized in Table 2-2. Further comment as to how these opportunities might be best integrated into the expanded Reactive Acid Tailings Program is made in Part 5 of the report.

TABLE 2-2

Opportunities for AWR Research at Canadian Base Metal Mines

Mine	Province	Opportunity
Mount Washington	BC	Select, install and monitor abatement system for a discrete AWR pile currently causing contamination problems. Solution will probably entail impervious cover plus downstream passive treatment of residual leachate.
Gibraltar	BC	Long-term benefits/implications of optimizing leach process in waste rock for metals recovery.
Equity Silver	BC	Monitoring effects of side slope sealing on highly reactive side hill dump. Monitoring effects of backfilling and flooding pit with AWR.
Westmin	BC	Monitoring effectiveness of covering AWR with layered tailings deposition.
Fecunis	ONT	Monitoring long-term effects of applying sewage sludge, garbage and lime/limestone additives to waste rock cover over pyrrhotite tailings.
Fraser	ONT	Application and monitoring of various chemical applications to AWR including lime/limestone, calcium phosphate non-basic, calcium phosphate, apatite, and bactericide.
Kam Kotia	ONT	Development, application and monitoring of long-term disposal measures for 200,000 tonnes AWR in association with acid generating tailings reclamation program.
Sherman	ONT	Opportunity to develop and monitor disposal system for highly reactive AWR.
Solbec Cupra	QUE	Opportunity to evaluate effectiveness of soil cover applied to AWR pile in 1978-79.
Doyon	QUE	Monitor effectiveness of bactericides to be applied in 1987.
Brunswick # 6	NB	Monitoring of controlled bactericide applications to AWR. Monitoring of backfilling pit with AWR and flooding. Implementation and monitoring of complete site reclamation involving several AWR management methods.
Heath Steele	NB	Opportunity to use several of 21 AWR piles to design, implement, and monitor various management techniques including covers.
Halifax Airport	NS	Observation of long-term effectiveness of NaCl and clay cover applied to acid generating slate pile.
Curraugh Resources	YT	Permafrost managementprogram. Applies directly to tailings but will have application to AWR behaviour in northern climates.
Nanisivik	NWT	Development, implementation, and monitoring of AWR abandonment measures in Arctic conditions.

PART 3

3.0 STATUS OF RESEARCH AND DEVELOPMENT

3.1 Literature Review

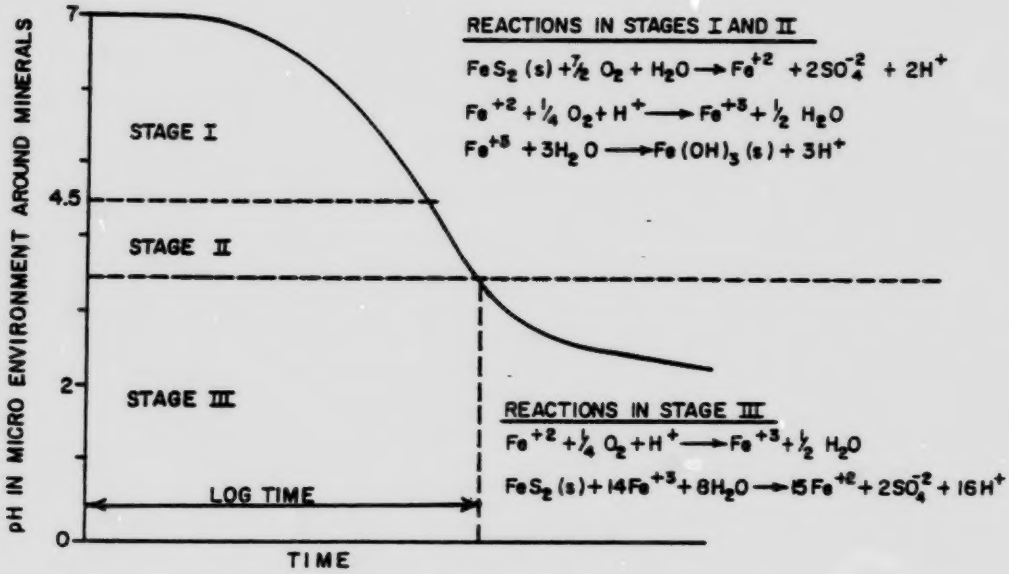
The mechanism of acid generation for sulphide materials has been extensively addressed in a number of recent reviews such as Monenco 1986 and Knapp 1987. The emphasis of this review will, therefore, be focussed on literature dealing with those aspects of acid generation specific to reactive waste rock management.

3.1.1 Overview of Acid Generation in Sulphide Wastes

Kleinmann et al., 1981, identified three stages in the generation of acid mine drainage. In the first stage, chemical and, or, biological oxidation of pyrite and other sulphide minerals slowly produces acid (Figure 3-1). This acid may initially be neutralized by carbonate minerals in the rock. After the carbonates are consumed, the process enters the second stage. As the pH drops in the microenvironment around the sulphide minerals, populations of acid loving (acidophilic) bacteria such as Thiobacillus ferrooxidans which are omnipresent in the waste, begin to multiply. These bacteria can result in the rate of oxidation increasing by 50 times over that of the purely chemical reaction, thus leading to a further and rapid decrease in pH. At this point, the process enters the third stage. When the pH around the sulphides decreases to below 3, ferric iron remains in solution. Ferrous iron is converted by the bacteria to ferric iron which in turn oxidizes the sulphide minerals. The rate of acid formation is rapid in the last stage and is limited by the concentration of ferric iron.

The four equations in Figure 3-1 generally outline the acid production process with pyrite (FeS_2) as it occurs at coal mines, but describe only a few of the many sulphide oxidation reactions at metal mines. The mix of sulpnide minerals at metal mines accounts for the diversity in AMD quality (Ferguson and Erickson, 1986).

From the standpoint of controlling acid generation, it is important to appreciate that if the pH of the microenvironment of the reaction is higher than the optimal level for ferric oxidation (say, pH 4 or higher), the ferric iron will be precipitated as ferric hydroxide, thus eliminating it as an effective oxidant.



AFTER FERGUSON & ERICKSON,1987

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FIGURE 3-1

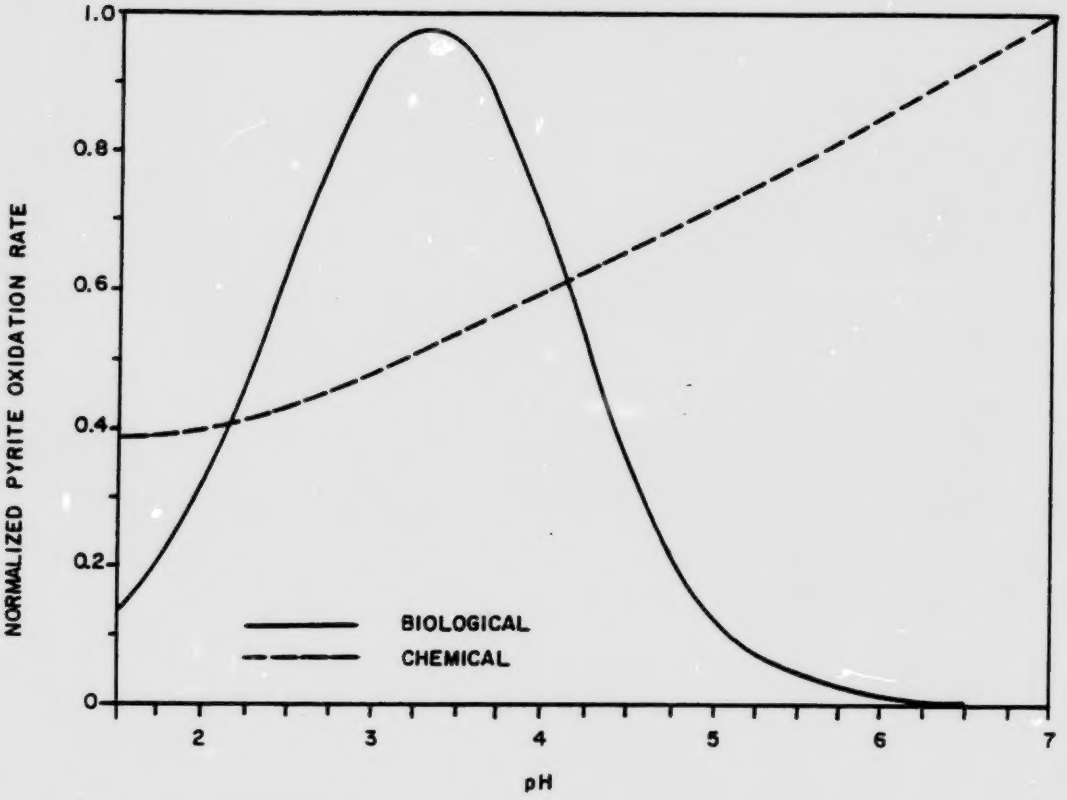
STAGES IN THE FORMATION OF ACID MINE DRAINAGE

3.1.2 Factors Affecting Oxidation

The sensitivity of the rate of sulphide oxidation to pH has already been identified and is shown diagrammatically in Figure 3-2. The morphology of the sulphide minerals, and particularly that of pyrite, is recognized as an important factor. Fine-grained framboidal type pyrite, for example, has been found to be particularly reactive (Infanger and Hood, 1980). Temperature has a major influence on the reaction rate which can double for each increase of 10°C (Morth, 1965). The amount of oxygen available at the pyrite surface is also important as is the rate at which the reaction products are transported away from the reaction site (Knapp, 1987). The reaction is also influenced by microenvironmental factors such as the exposed surface area of the sulphides; composition of the waste rock, and in particular its buffering capacity; humidity; and the availability of carbon dioxide, nutrients, and trace elements essential to microorganism growth.

John, 1987, reports that the most critical factor in the oxidation of pyrite is the availability of oxygen and that the oxygen concentration required for the support of bacterially mediated oxidation is 0.5 mg/l (1.6 mol fraction percent). Nicholson, 1984, presents a plot of oxidation rate versus oxygen concentration (Figure 3-3) showing the relationship to be non-linear. He attributes this to be the result of complex adsorption-desorption mechanisms at the reaction site.

An insight into the factors influencing the generation of pollutants in waste rock dumps can be obtained by reviewing the literature on heap leaching for beneficiation purposes. The efficiency with which air is drawn into a heap leach pile is recognized as a key parameter, although the relative roles of air diffusion through the dump interstices as compared to air convection brought about by the exothermic oxidation of pyrite is open to some debate (Cathles and Apps, 1975). Good leachate qualities for beneficiation are dependent on maintaining air as the main source of oxidation rather than dissolved oxygen in the leach solution; a factor which should be kept in mind when trying to minimize waste dump contaminate leaching. Cathles and Schlitt, 1980, conclude from the development of a two-dimensional dump leach model that beneficiation leaching of copper from low grade dumps is fastest for dumps of 15 - 30 m



AFTER KNAPP, 1987

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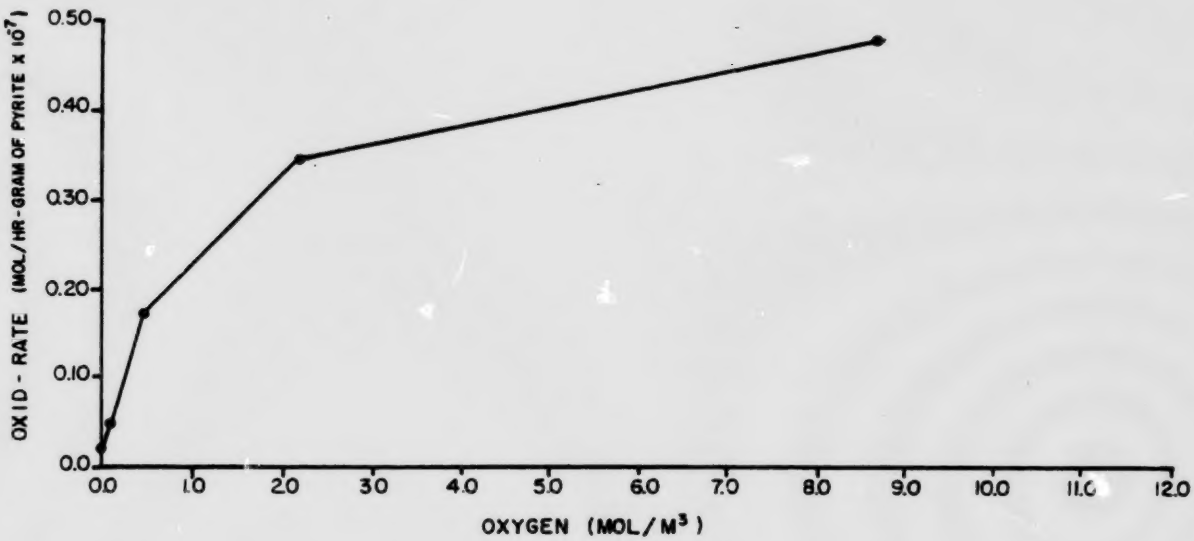
FIGURE 3-2

EFFECT OF pH
ON BIOLOGICAL & CHEMICAL OXIDATION RATE



AFTER NICHOLSON, 1984

NOLAN, DAVIS & ASSOCIATES

FIGURE 3-3

OXIDATION RATE VS. CONCENTRATION OF OXYGEN IN THE GAS PHASE height; that permeability of the dump is very important, and that leaching is facilitated if the leach solutions are preferentially supplied to the hot, near-edge portions of the dump.

Thus, one would conclude from these data that to minimize leachate production in acid waste rock piles, one should reduce the permeability of the dump to air; try to prevent the exothermic oxidation reaction from significantly raising the dump temperature; minimize leachate transport; and prevent the ingress of seepage to the outer portions of the dump.

3.1.3 U.S. Experience With Acid Coal Spoils

Most of the literature base specifically addressing the issue of acid waste rock management has developed as a result of surface coal mine operations in the eastern United States. Although the basic objectives are the same, the practical considerations in relation to materials handling are quite different at a strip mining operation to those of a hard-rock open pit situation common to base metal mining. Furthermore, coal overburden in the eastern U.S. usually contains a large percentage of slaking mudstones or shales which compact over time resulting in natural reductions to infiltration and oxygen penetration (Robertson, 1987). Hard rock waste dumps normally remain highly permeable to air and water unless preventative measures are applied.

Despite these differences, the literature pertaining to pyritic coal wastes does highlight some waste management principles that are applicable to hard-rock operations. Cathles, 1982, for example, compares the management of coal spoil piles to beneficiation leaching and emphasizes the importance of reclaiming pyritic spoils as soon as possible after mining in order to limit the oxidation of the spoil to the limited potential of "buried air". He recommends the following three steps to reduce the amount of acid generated:

1. bury and cover the spoil as soon as possible after mining

2. compact spoil piles to eliminate air convection and reduce oxygen diffusion into the pile

3. consider the addition of bactericides to the pile

Cathles, in the same reference, also states that while the burial of coal waste below the water table is not always possible, "a few feet of water will reduce the pyrite oxidation rate effectively to zero".

Erickson, 1987, confirms that the current practice for the disposal of coal spoils in the U.S. now involves placement in optimized sites, compaction of the material during placement, followed by covering and revegetation.

Infanger and Hood, 1980, report that the sequence in which overburden materials are placed in relation to acid coal spoils has a marked effect on leachate quality. In general, the more alkaline materials should be placed above the acid-producing material, and if possible, the pyrite layer should also be placed below the water table.

Many coal mine spoils in the Appalachian region of the U.S. produce low amounts of acidity (less than 30 mg $CaCO_3$/l per 100 g sample). In such cases, it has been demonstrated that mixing in the equivalent of a 0.3 m layer of limestone will inhibit acid production in the top 3 m of spoil, thus effectively arresting the leachate problem (Williams et al, 1982). Other researchers on acid coal spoils indicate that the placement of soil covers in excess of 0.6 m provides a preferable treatment technique to the use of ameliorants such as lime, limestone, or sewage sludge (Apel, 1982).

Revegetation can provide an aesthetically pleasing cover to reclaimed spoil areas and will stabilize the surface from erosion. However, it is recognized by a number of authors (e.g. Farmer and Richardson, 1981) that revegetation in itself will not curtail acid generation in spoil piles. This finding is supported by Veldhuizen et al., 1987, in relation to revegetation trials on acid-generating base metal tailings. They conclude "direct vegetation of reactive tailings does not restrict pyrite oxidation nor does it limit water infiltration to significantly reduce water flow from the impoundment."

Carruccio and Geidel, 1987, report the use of alkaline trenches as a successful approach to shifting high acid leachate spoil systems towards more alkaline regimes. This initially involves placing limestone-filled trenches at appropriate locations on a spoil dump such that alkaline charged surface drainage is directed into the reactive zones of the dump. Understanding the hydrogeological characteristics of the dump and the area in which it is situated is essential in correctly locating the trenches.

As previously stated, the materials handling implications of coal spoil piles are quite different from those normally associated with waste rock piles at base metal mines in Canada. However, the experiences of coal mine reclamation workers in the U.S. and elsewhere does highlight the following principles in relation to acid waste rock management:

- Siting of the disposal area is of paramount importance, particularly with respect to local surface and groundwater hydrology.
- Compaction of the wastes to minimize the availability of air is important.
- Disposal below the water table is extremely beneficial.
- Placement of soil covers of at least 0.6 m over the spoil improves leachate characteristics.
- Direct vegetation of sulphide wastes has no beneficial effect on leachate characteristics.

3.1.4 Hard Rock Waste Management

There is very little literature on the management of reactive hard rock wastes typical of base metal mines in Canada. Egar and Leppakko, 1981, report a series of leaching tests undertaken on experimental stockpiles containing metal sulphide wastes at the Minnamar site in Northeastern Minnesota. Six test stockpiles of 1600 to 2100 tonnes of low grade copper-nickel material were constructed on hypalon liners. One pile was covered with 18 cm of topsoil, another with 29 cm of coarse sand, and a third with 30 cm of sandy till over 28 cm of coarse sand. The other three were left untreated. The coarse sand cover did not reduce sulphate or nickel release rates but the other two treatments were effective in reducing the quantity of leachate generated and the topsoil cover provided the lowest overall leachate release rates.

Work undertaken on the covering of two pyritic waste rock dumps at the Rum Jungle mine in the Northern Territory of Australia has been reported by several authors. Harries and Ritchie, 1986, describe the reclamation measures applied to the two dumps which contain approximately 4×10^6 tonnes and 0.8×10^6 tonnes of material. Essentially, the sides of the dumps were worked to give a maximum slope of 1 vertical to 3 horizontal with a berm half way down the slope. Engineered drop structures were provided to take surface water from the berm to the base of the dump. The dump was then covered with 3 layers of material:

- on the top: 225 mm compacted clay followed by 253 mm of clayey sand and a minimum of 150 mm of gravelly clayey sand

- on the sides: 300 mm compacted clay followed by 300 mm clayey sand and 150 mm broken rock

Vegetation was established on the surface to provide protection and improve the aesthetics of the dump.

Prior to the capping operations, temperature probes and gas ports were installed in a number of holes in each dump. Temperatures of about 50°C were recorded at 14 m depth in the larger dump with heating also identified closer to the surface. Oxygen and carbon dioxide measurements provided some interesting insights into gas transport mechanisms within the dump. In some areas, it was evident that oxygen was supplied primarily by diffusion from the surface, whereas in others, thermal convection was evident. Oxygen concentrations varied from virtually zero to a mole fraction of 20 percent. Carbon dioxide levels were generally between 1 and 3 orders of magnitude higher than levels in atmospheric air. This was thought to be due to the action of acid on dolomite within the dump.

Rehabilitation of the dump took place between August 1983 and April 1984. Oxygen concentrations in the dump decreased dramatically to the 1 percent level at all sampling points as soon as the clay cover was installed (ref. Figure 3-4). Temperature measurements responded less dramatically but showed a steady decline through to the last reported measurements in early 1985 (ref. Figure 3-5). It was concluded that the cover effectively stopped air transport through the dump both by diffusion and by thermal convection and thereby lowered oxidation rates within the dump. However, the authors report that air is penetrating the cover in

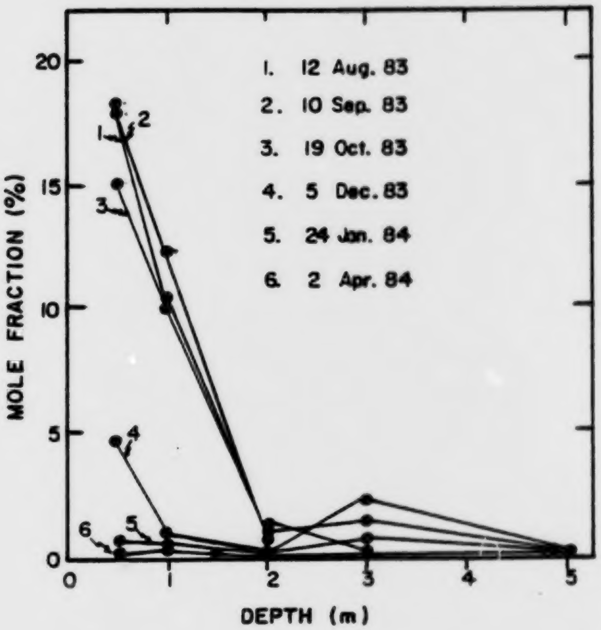


FIGURE 3-4: OXYGEN CONTENT AT VARIOUS DEPTHS WITH TIME

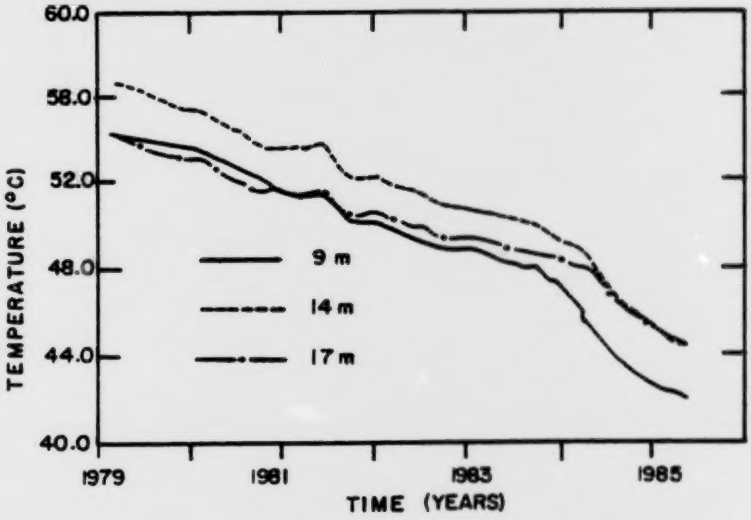


FIGURE 3-5: INTERNAL TEMPERATURE AT VARIOUS DEPTHS WITH TIME

AFTER HARRIES & RITCHIE, 1986

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FIGURES 3-4 & 3-5

RUM JUNGLE CLAY-CAPPED DUMP RELATIONSHIPS some areas, possibly due to root penetration, and advise that it is not yet clear whether the oxidation rate will remain at a low level over the course of time.

Engineering details of the cover and drainage systems applied to the Rum Jungle dumps are described by Allen, 1985, and the surface treatments by Ryan, 1986.

Smith and Van Zyl, 1983 provide the following design criteria for acid waste rock dumps:

Criteria	Approach
1. Exclusion or limitation of oxygen availability	- compaction of waste - low permeability covers - flooding
2. Limitation of water ingress	- minimize catchment area - low permeability cover - site in g/w recharge area - g/w interception systems - low permeability base
3. Exclusion of bacterial Activity	- as for exclusion of oxygen

Similar criteria are used by Bell, 1987, to derive the following approach to the cellular design of acid waste rock dumps:

- placement of the waste in uniform layers with compaction to reduce the pore space and thus minimize air convection and oxygen transfer within the pile.
- placement of continuous horizontal and vertical barriers of compacted impermeable till to reduce the ingress and movement of moisture and air within the pile.
- use of bactericides or other inhibitors on the waste prior to placing the next impermeable layer.
- sealing and vegetation of side slopes as soon as they become inactive.

- final capping and doming of the waste pile with impermeable material.
- establishment of self-sustaining vegetation on the final cover.

The author states that the practicality of this approach depends on the availability of impermeable materials within a reasonable distance of the site. He also stresses the need to locate and design the dump so as to facilitate the collection of any contaminated leachate since there is no evidence to date that even measures such as those described will absolutely prevent the generation of acid leachates.

Patterson, 1987a, reports a number of control measures and experiments that have been conducted with respect to the acid waste rock dump at Equity Silver in British Columbia (ref. Section 2.1.2). He reports that the use of till to provide horizontal seals within the dump and to provide a cover to the slopes represents a small incremental cost over and above normal operating expenditures. There has been a slight downward trend in acidity and metal levels as a result of applying these measures at Equity Silver and temperature probes placed in the dump have shown a slight decline from the 55°C levels previously recorded.

Application of sodium lauryl sulphate to the Equity Silver dump was tested after laboratory simulations produced promising results. However, the spoil piles could not be effectively saturated and the surfactant biodegraded rapidly under the acidic conditions present (ref. Section 4.6 for further review of the use of bactericides).

Patterson also reports on laboratory scale column tests conducted at Equity Silver to test the efficiency of injecting AMD sludge into the waste rock. Results show a drop in metal levels in the leachate immediately following application but a subsequent rise once the alkalinity in the sludge is depleted, resulting in higher metal levels than the pre-injection conditions. Similar column tests undertaken at Equity show that minimal oxidation of pyritic waste occurs if it is placed below the water table (ref. Section 4.3.2).

Taylor, 1984, in describing the acid waste management systems at the Gibraltar Mine in British Columbia, states that the possibility of sealing the large waste dumps (ref. Section 4.5.1) was considered and rejected as logistically unfeasible due to all of the dumps being active.

The decision was therefore made to treat any contaminated leachate from the dumps rather than apply preventative measures.

3.1.5 Prediction of Acid Drainage

The ability to predict whether or not specific wastes will become acid producing is extremely important, not only to the siting and design of waste management facilities but also to the potential economics of mine development. Ferguson and Erickson, 1987, provide a comprehensive review of currently available static and kinetic predictive techniques including the following methods:

Test	Current Use
B.C. Research Confirmation Test	- Frequently used for metal mines in Canada
Shake Flasks	- Infrequently used for metal mines in Canada
Soxhlet Reactor	- Infrequently used in Appalachian coal fields
Columns/lysimeters	- Relatively common in Canada and U.S.
Test Plots	- Very infrequently used

The technique of acid-base accounting is described by Freeman, 1987, and provides a graphic method of selecting overburden materials for coal mine reclamation purposes. Albright, 1987, describes the development of a hitherto, unpublished back-titration method as applied to Halifax formation slates. This test treats the sample with acids stronger than those commonly observed in nature, thus promoting acid-base reactions which occur only under strong acid conditions. It is argued that the test is more conservative than the BC Research test which is currently used as the standard screening test for potentially acid-generating material in Canada.

At the present time, the predictive techniques described above enable minerals to be broadly categorized as potentially acid producing or consuming, but are not always conclusive when the sulphide and carbonate contents are in critical balance. Ferguson, 1985, describes a series of tests in which static and kinetic tests were conducted on 22 rock samples from both active and inactive mine sites in BC and the Yukon. The tests correctly predicted the formation of acid drainage in all but six cases, of which three were incorrect and three inconclusive.

In a later paper (Ferguson and Erickson, 1987), it is concluded that the static tests may be useful for qualitative predictions but not for estimates of actual mine water quality.

Mathematical models have not been used extensively for qualitative predictions of acid drainage quality to date, although a number are available (Carruccio, 1984; Jaynes et al., 1984a) & b); Ricca & Shultz, 1979; Halbert et al., 1983; Nicholson, 1984; Cathles, 1979; Davis & Ritchie, 1983). A probabilistic, predictive mathematical model for the assessment of acid production in tailings was developed as a part of the National Uranium Tailings Program (John, 1987). This enables the calculation of anticipated concentrations of acidity and pH levels with time for sulphide-bearing tailings. It is a detailed model based on thermodynamic and kinetic data. It is user-friendly and may, with modification, have application as the basis of a model for acid waste rock.

3.2 Current State-of-the-Art

The application and systematic monitoring of preventative management methods for acid waste rock are in their infancy. In fact, the work conducted at Rum Jungle in Australia, as reported by Harries and Ritchie, 1986, is the only situation identified in which a complete AWR management system has been applied and monitored. Even this example is inconclusive as to the long-term effectiveness of the cover to control air infiltration and therefore acid generation. Despite this concern, there is evidence that well-constructed covers and seals can be effective in reducing the rate of oxidation in AWR piles. There is general recognition of the following factors:

- Siting of the disposal area is of paramount importance, particularly with respect to local surface and groundwater hydrology.
- Compaction of the wastes to minimize the availability of air is important.
- Disposal under water or in permanently saturated conditions is extremely beneficial.

- Use of soil covers improves leachate characteristics.
- Direct vegetation of sulphide wastes does not in itself improve leachate characteristics.

The use of sealed waste dumps constructed on a cellular basis appears to have promise but has yet to be applied and monitored on a full-scale or pilot application.

There is mounting evidence that the disposal of acid generating wastes underwater provides the most assured approach to the long-term control of oxidation. This evidence applies specifically to reactive tailings, and there are no documented cases relative to acid waste rock, although the same principles should apply.

Bactericides (ref. also Section 4.6) have been shown to be effective for the interim control of bacterial oxidation in a number of situations, but there continues to be some doubt as to their effectiveness in waste rock due to difficulties in wetting the active surface area and preventing their degradation under acid conditions.

The ability to accurately predict the extent and form of acid generation requires considerable refinement, particularly in relation to marginal situations and the impact of climatic conditions in the northern regions of Canada.

At the present time, there is no proven method of AWR management for which backup leachate collection and treatment is not required, with the possible exception of underwater disposal. The effectiveness of passive treatment systems to handle residual leachate flows is also unproven under Canadian conditions.

Despite these apparent shortcomings, the knowledge does currently exist to site and design AWR dumps so as to minimize the generation of contaminated leachates and to provide environmental protection through conventional collection and treatment of leachate residuals as necessary. Future advances must, therefore, focus on the testing and monitoring of various AWR management techniques so as to provide performance and design criteria, and on the development of passive treatment methods so that leachate residuals can be made innocuous without the need for ongoing human intervention.

PART 4

4.0 ALTERNATIVE AWR MANAGEMENT METHODS

4.1 Introduction

This part of the report reviews a number of alternatives for the long-term management of acid waste rock. It is important to appreciate that the disposal of waste rock is extremely mine-specific in terms of its economic impact on the operation, the options available for disposal, and the environmental implications of the disposal system.

At open pit operations, the cost of loading and hauling waste rock can fall in the range of 35 to 80 cents per tonne which can represent 35 to 60 percent of the total cost of mining. Any measures which significantly increase waste rock disposal costs, such as increased haulage distances, will therefore, impact noticeably on the overall cost of metal production.

Acid waste rock can be generated at underground mines in the form of development rock as well as at open pit mines. Relative volumes of material to be handled vary significantly from mine to mine; but in general terms, the amount of waste generated at open pit operations is significantly larger per unit of ore processed and will normally be a continuing function of the mining operation. For this reason, the waste rock disposal area at open pit operations must be kept active throughout the life of the mine. Preventative measures for acid leachate generation must be designed around this requirement.

Depending on mine geometry, an open pit operation will typically generate about 2-2.5 times the volume of waste rock as mill-feed, although stripping ratios as high as 6 may be encountered for high grade ores. This compares to the approximate 90 percent of mill-feed normally represented by tailings. Thus, at many open pit operations in sulphidic areas, the shear volume of waste rock will tend to polarize it as the major waste management issue pertaining to the site. Yet, as the foregoing sections indicate, there are currently no established methods for the long-term management of acid waste rock other than the collection and treatment of leachates in perpetuity.

It is in this perspective that the management strategies outlined in the following sections must be reviewed.

4.2 In-Situ Neutralization

As a concept, in-situ neutralization of acid-generating waste rock can involve either the addition of alkaline materials such as limestone, or other locally available material, to the waste rock as it is placed in the storage area, or alternatively the blending of acid-consuming material developed in the course of the mining operation. In either case, the objective is to mix sufficient acid-consuming material into the waste pile to uniformly offset the acid-generating potential of the waste.

The technique of blending available mined materials is quite common in coal strip mining. The acid-base accounting method of prediction outlined in Section 3.1.5 is used to determine the manner in which available materials should be managed to achieve the most favourable mix at the post-operational stage. In coal stripping operations, this approach is often attractive because the required acid-consuming material is available on site and must be stripped and relocated as an integral function of the mining operation. The incremental cost of achieving in-situ neutralization, assuming sufficient material of adequate acid-consuming potential is available, is therefore represented only by any changes that need to be made to the mining plan to achieve adequate blending.

This opportunity is seldom available at base metal hard-rock mines, although in many instances the characteristics of waste rock will vary from zone to zone within a given mining operation.

At large open pit operations where acid waste rock volumes will exceed 100 million tonnes over the life of the mine (ref. Table 2-1), the cost of mixing off-site neutralizing materials into the waste as it is placed is prohibitive. For example, at the Equity Silver Mine, it was calculated that in excess of 7 million tons of lime, at a delivered cost in the order of $4 billion, would be required to neutralize the total net acidity in the final waste pile. While this figure may be exaggerated by the fact that a large percentage of the acid-producing material would not be available due to the size of the rock pieces, the general magnitude of the figure is testimony to the impracticality of this approach.

Despite the likelihood that cost will render this approach impractical at a majority of base metal mining operations, the opportunities for in-situ neutralization should always be examined at the conceptual design stage. In the event that acid-consuming materials are economically available as mining by-products or from other sources, this approach offers the ideal preventative concept in that long-term stability of the waste can be assured.

The availability of reliable techniques to predict the relative acid producing and consumptive characteristics of the materials to be blended is fundamental to this management approach.

4.3 Underwater Disposal

This concept can include disposal into natural water bodies, flooded mine workings, or specifically designed retention systems.

There is a steadily accumulating volume of field evidence that disposal of reactive mine wastes under water curtails oxidation to virtually zero levels. This is due to the very low diffusivity of oxygen through water (approximately 2×10^{-6} cm/sec). There are, however, a number of factors to be considered including the effects of turnover in re-oxygenating the bottom waters of natural lakes; the effect of sulphate reducing benthic organisms; and the fact that the diffusion of oxygen through water is not absolutely curtailed. The balance of these factors under practical conditions is not well understood at this time.

4.3.1 Disposal into Natural Waters

There are a number of sites in Canada where reactive acid tailings have been placed in lakes or coastal waters. All studies undertaken to date on these deposits indicate that the finely divided tailings have remained in an unoxidized condition over a period of many years. An example is Buttle Lake in British Columbia which had been the recipient of reactive tailings from the Westmin Mine from 1966 to 1984. The practice of discharging tailings into the lake was stopped due to public and regulatory concern that it was the cause of elevated zinc levels in the lake waters. This increase, however, was subsequently found to be due to leachate from a land-based waste rock storage pile which was later intercepted and treated. Studies of undisturbed and unexposed core samples from the lake bottom showed that the tailings interstitial water was more alkaline and contained significantly lower levels of metals than the overlying lake water and that there had been no significant chemical leaching in the tailings or release of metals into the lake water (Stokes & Hallam, 1984).

The Buttle Lake data are supported by other evidence resulting from studies undertaken in Manitoba as a function of the RATS program. Work on the oxidation profiles in abandoned tailings deposits indicates a general lack of oxidation within the saturated zone of the tailings (Dave et al., 1986; Boorman & Watson, 1974), thus further supporting the argument that submergence in water is an effective management tool for the long-term storage of reactive acid wastes.

There are no known situations where acid generating waste rock has been deposited in natural waters and the results monitored over a period of time. However, since the relative surface area of waste rock is far less than that of tailings per unit weight, one could expect that the reactivity of waste rock underwater would be even less than that of tailings of similar acid-generation potential.

Despite the attraction of using natural water bodies for the disposal of acid waste rock from the biochemical stability viewpoint, there are several obvious short-comings with this approach; not the least of which is the fact that relatively few metal mines are located within economic haulage distances of suitable natural bodies of water. A second serious limitation is a general concern on the part of the public and many regulators over the use of natural water bodies for any form of waste disposal, and it can hardly be argued that the disposal of large volumes of waste rock will not have a significant physical impact on the benthic conditions of a lake or coastal marine environment.

In circumstances where natural water bodies do exist in reasonable proximity to mining operations, the relative merits of using them for reactive waste disposal should be weighed against the cost and long-term environmental implications of land-based disposal.

Investigative work on the long-term behaviour of reactive mine wastes that have been deposited under water should be continued so as to develop a full understanding of its implications to the chemistry and long-term benthic ecology of the receiving systems. Large-scale laboratory simulations such as those currently in progress for sulphide tailings at the Mineral Sciences Laboratory of CANMET in Ottawa should also be maintained.

4.3.2 Disposal into Flooded Mine Workings

Abandoned mine pits will normally flood back to the natural groundwater table once active mining ceases, unless the workings have significantly altered the properties of the pit area (as in the case of side hill pits), or ongoing mining operations in the region continue to draw down the water table.

Flooding of an abandoned pit will normally create an ideal disposal area for waste rock. Column and aquarium tests conducted at the Equity Silver Mine (ref. Figure 4-1) prior to backfilling their Southern Tail pit indicated that reactive rock placed below the water surface would remain stable. Subsequent evidence from the backfilling operation has supported this finding (Patterson, 1987b).

The situation at Equity Silver, however, probably typifies many open pit mining operations in that the mining operation lowered one side of the pit such that the flooded volume available for underwater waste rock disposal was relatively small compared to the volume of rock produced. There are, in any case, a number of problems often associated with this approach:

- At single pit operations, it is necessary to store reactive waste rock for the life of the mine and to then incur rehandling costs in moving the material back to the pit at a time when the operation is producing no revenue.

- If all waste removed from the pit is reactive, the swell factor (usually about 30 percent) will result in an excess volume of reactive waste to available underwater storage, particularly as the pit will likely flood to point less than full.

- Any sulphides in the pit walls above the final water elevation will oxidize causing a deterioration in water quality unless preventive measures can be applied.

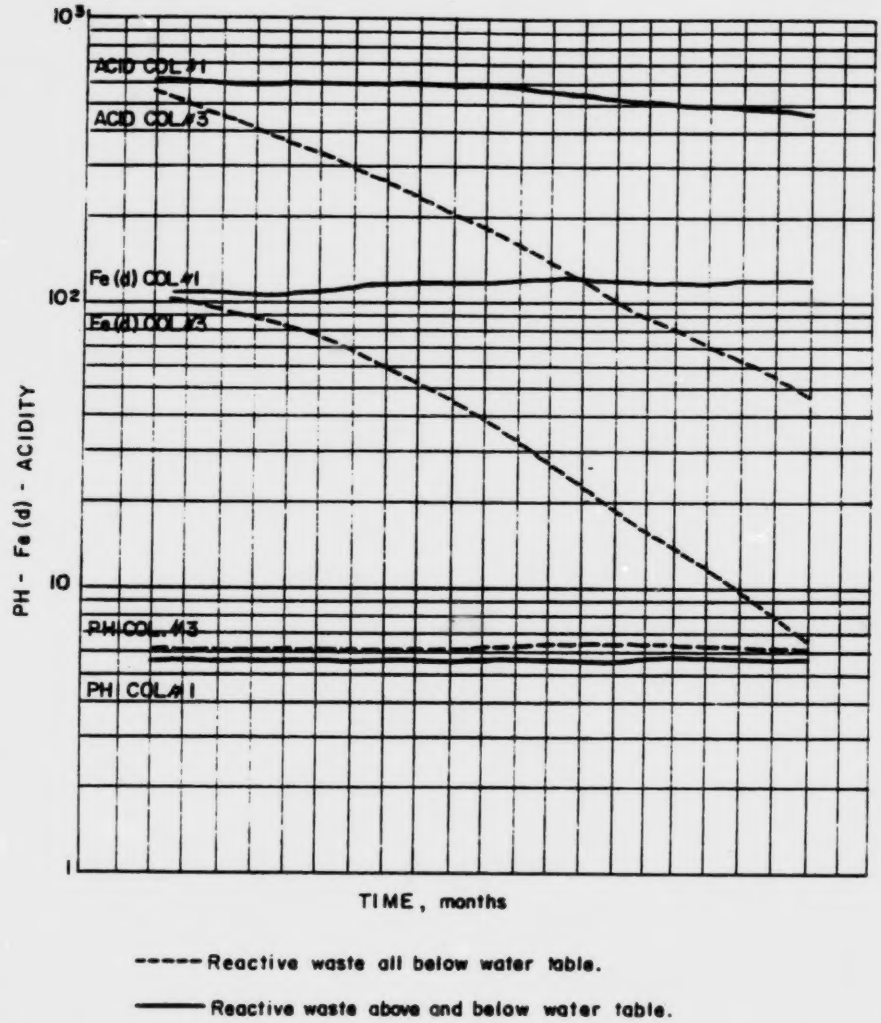

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FIGURE 4-1

TESTS ON BACKFILLING AWR INTO FLOODED PIT
AT EQUITY SILVER MINE

- Backfilling and flooding precludes future underground development that might be associated with the ore body.

The opportunity provided by flooded open pits for acid waste rock disposal is, therefore, very mine-specific and will seldom offer a total solution to the problem. It will, however, provide an attractive means to reduce the volume of waste requiring other management measures at many sites and every effort should be made to more fully understand the generic implications of flooded pit disposal to groundwater systems, as well as ways to control sulphide oxidation in pit walls, surface sealing techniques, etc.

Where the acid generation reaction is well-established in waste rock prior to its being placed underwater, it may be necessary to apply sufficient neutralizing material to ensure that ferric iron oxidation is curtailed as a function of the backfilling operation. Lime was added to the Equity Silver pit as it was backfilled with a view to creating neutral pH values in the water already in the pit bottom. These values have been maintained despite there being oxidizable materials in the pit wall above the water table.

The opportunity to dispose of waste rock in pits above the water table often occurs and criteria to minimize the generation of acid in these circumstances are required.

It is generally recognized that a fluctuating water level within a reactive waste material (tailings or waste rock) is the worst possible situation in that conditions in the wetted zone are ideal for the generation of acid and flushing of the reaction products. Thus, where pits are to be filled above and below the water table, it is essential that the range of water fluctuation be defined and a layer of non-reactive material placed in this zone so as to avoid the fluctuation of water through acid generating wastes. This was achieved at the Equity Silver Mine by placing a one-metre layer of inert gabbro at the phreatic surface, which in that case was controlled at a constant level by a low point in the pit wall.

The need to seal the surface of backfilled open pits to minimize exposure of the backfill to air and rainfall is recognized. Surface drainage should also be diverted away from the pit to minimize any flushing action or fluctuation of the water table within the backfilled material. Sealing techniques are reviewed in Section 4.5.

4.3.3 Man-made Underwater Disposal System

Since underwater disposal of reactive mine wastes appears to provide a means of achieving long-term biochemical stability of the waste, the practicality of providing engineered underwater disposal systems for acid waste rock should be considered.

Potential disadvantages include the cost of providing very large subaqueous storage volumes and concerns with respect to the long-term safety and stability of man-made retaining systems.

An underwater waste rock storage system would consist of an impoundment of the appropriate volume created by one or more dams. Spillway facilities would have to be incorporated to safely route the maximum flood anticipated for the watershed controlled by the system. Conservative design criteria would have to be used to ensure that the system required a minimum of maintenance over the long term.

A system such as this was proposed for the perpetual storage of reactive tailings at the Curraugh Resources property in the Yukon. In this case, a dam of 58 m height would have been required in order to flood back over existing and proposed tailings. The spillway system proposed consisted of a flow-through rockfill zone with a "window" below the crest to allow for the access of water to the spillway zone underneath the winter ice cover. Conservative design features included 1 vertical to 3 horizontal side slopes and allowance in the design for overtopping despite the capacity of the flow-through spillway to carry the maximum probable flood.

Total cost would have been about $50 million and for this reason alternative management strategies are currently being evaluated for the site.

Obviously, the cost and practicality of using man-made underwater disposal facilities must be evaluated on a site-specific basis. It is possible that the option will prove attractive in cases where there is favourable topography and the volume of acid waste rock is relatively small, as might be the case for reactive development rock at an underground operation. Incorporation of flooded waste rock disposal facilities with the tailings system might prove advantageous in some such circumstances.

It is recommended that criteria for the design of long-term flooded disposal systems be developed on an industry-wide basis.

4.4 Use as Underground Mine Backfill

In circumstances where acid waste rock exists in close proximity to an underground mining operation, the possibility of using it as mine backfill can be considered. This situation might occur where an open pit operation is close to a separate underground mine; where an open pit operation with waste rock stored on surface has gone underground; or where early development rock from an underground operation can later be used as backfill.

The normally preferred criteria for mine backfill are as follows:

- non-reactive
- non-friable
- minus 15 cm size range
- minimum transportation costs

The use of reactive acid rock as backfill is a compromise from the mining standpoint as it can lead not only to the generation of highly contaminated acid drainage within the mine, but also to the possibility of an uncontrolled exothermic reaction within the backfill. The rock will tend to retain more heat when used as a backfill than in a surface dump.

In many sulphide ore bodies, the mine drainage will be acid so that the increased loadings resulting from reactive waste rock backfill may result only in increased treatment costs. However, in situations where there is sufficient buffering to maintain the minewater in an alkaline or near-neutral condition, the use of AWR as backfill would probably not be attractive as it would likely lead to the need to install stainless steel mine drainage pumps and lines.

Exothermic reactions due to the use of reactive backfill have occurred at several metal mines in Canada including the Brunswick No.12 mine in New Brunswick and the Sullivan Mine in British Columbia. The Brunswick No.12 mine was using acid waste rock from their No.6 open pit operation some 6 miles distant but have now stopped the practice in favour of custom quarried non-reactive backfill.

It is not known if the use of AWR for cemented backfill would avoid the disadvantages outlined above but this may warrant investigation as would the development of general criteria for the use of AWR for underground backfill.

4.5 Waste Pile Sealing Techniques

To be totally effective, any sealing system for acid waste rock storage systems must eliminate the throughput of moisture and reduce oxygen levels within the systems to less than 0.5 milligram per litre. Ideally, the sealing system should be able to maintain this level of performance without maintenance in perpetuity.

To meet these requirements in a normal side hill or free-standing acid waste rock dump, it is necessary to provide the following:

- top cover to prevent direct rainfall infiltration and air diffusion
- sideslope cover to prevent rainfall infiltration, air diffusion and induction
- stabilization of top and side covers to prevent wind and water erosion
- system to prevent penetration of the seals by roots, animals, or other means

To date, there are no recorded cases of totally effective sealing systems for acid waste rock dumps. The best documented situation is the Rum Jungle pyritic waste piles in Northern Australia (ref. Section 3.1.4). In this instance, the clay cover reduced the oxygen mole fraction in the pile to as low as 0.1 percent in one area and to generally less than 1 percent throughout. The reduction in oxygen concentration with time is shown in Figure 3-4. It is disturbing that Harries and Richie (1986) report that only one year after completion of the cover, air was penetrating through the cover, possibly due to root penetration, and its long-term effectiveness was, therefore, open to question.

4.5.1 Types of Cover

A variety of materials that might be considered for providing surface covers to acid waste rock piles is listed in Table 4-1 along with their advantages and disadvantages.

The effectiveness of soil covers as oxygen barriers will be influenced by the moisture content maintained in the cover. Layers that can be maintained in a saturated, or near-saturated, condition will be far more effective in this regard due to the low diffusivity of water to oxygen. In this regard, composite covers designed to prevent the desiccation of clay or till have been suggested as potentially beneficial (Gillham, 1987). A composite cover designed in this way might consist of the following:

surface	vegetation	- stabilize surface/aesthetics
20 cm	topsoil	- prevents desiccation of clay
20 - 30 cm	coarse material	- root barrier
50 - 200 cm	clay/till	- provides saturated seal
20 - 30 cm	coarse material	- capillary break

Composite covers such as this have yet to be evaluated under field conditions.

A review of the advantages and disadvantages listed in Table 4-1 indicates that some form of regular maintenance is required to preserve the long-term effectiveness of most forms of cover.

The lifespan of HDPE (High Density Polyethylene) covers is unknown, but may be in the order of 100 years if properly placed on selected bedding material and protected with a top covering of sand and/or till. Extremely flat side slopes would be required to ensure stability of a protective cover placed over HDPE. Although the present value of the replacement cost of a synthetic cover on a 100 year basis may be quite small, the monitoring of the condition of the cover, administration of the fund and actual implementation of the replacement are impediments to this approach, despite the fact that it can provide a relatively positive seal to moisture penetration.

Where clay or till are available, they would appear to offer a more favourable balance between performance, practicality, and relative

TABLE 4-1

Alternative Cover Materials
(depending on local availability)

Cover Material	Permeability to Water (m/sec)	Advantages/Disadvantages
compacted clay	$10^{-9} - 10^{-11}$	Large quantities problematic in many areas. Subject to erosion, cracking and root penetration. Good sealing if protected and maintained.
compacted till	$10^{-7} - 10^{-9}$	As above but generally more permeable.
compacted topsoil	$10^{-5} - 10^{-8}$	As above but less robust, more peameable. Questionable longevity.
peatland bog	$10^{-5} - 10^{-6}$	Need to maintain in saturated condition. Normally impractical for elevated waste dumps and side slopes.
concrete	$10^{-10} - 10^{-12}$	Subject to cracking, frost and mechanical damage.
asphalt	10^{-20}	As above.
HDPE synthetic cover	Impermeable	Requires proper bedding and protective cover. Highly impermeable. Lifespan unlikely to exceed 100 years. Subject to root and mechanical penetration.

ease of maintenance. However, from the standpoint of engineering risk, it can be argued that relying on the long-term integrity of a highly vulnerable single-surface cover to provide protection of the environment against the impact of acid leachate will, in most cases, be unacceptable.

Over the course of several years, most soil-type covers will be invaded by trees and larger-rooted plants which will endanger the integrity of the cover, particularly if they are uprooted for any reason. Burrowing animals can also pose a threat if they are attracted to well-graded soils in the cover.

The risk and implications of cover failure can be reduced by providing a series of seals throughout the dump through the use of cellular construction as reviewed in the following section.

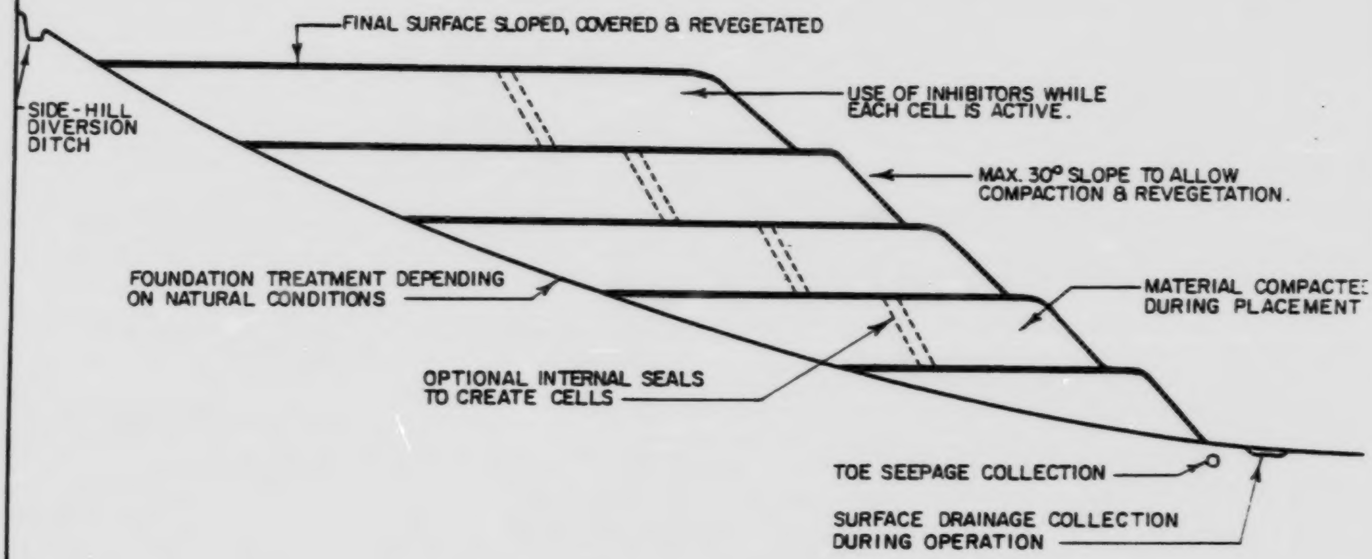
4.5.2 Cellular Construction

The construction of acid waste rock dumps in cellular units as described by Bell, 1987 (ref. Section 3.1.4), offers a number of advantages if adequate supplies of a suitable clay, till, or other sealant are available within a reasonable radius of the dump. This approach not only limits the implications of local failures in the surface seal but also allows control to be exercised over the rate of oxidation as the dump is constructed, an extremely important consideration bearing in mind that the life of a mine can extend over several decades and that the oxidation process will start in the waste as soon as it is exposed. The size of each cellular unit should be decided on the basis of the reactivity of the waste and the rate of accumulation. Each cell should represent not more than 6 months production. Depending on the reactivity of the waste, bactericides can be used to control acid generation in the active cells prior to their being sealed (ref. Section 4.6). A conceptual cross section of a cellular dump is shown in Figure 4-2.

It must be stressed that the effectiveness of this approach has not been field tested but it is recommended that it be evaluated in situations where the availability of sealing materials permits.

4.5.3 Surface Stabilization/Dump Geometry

Soil covers used on waste dumps require protection against wind and water erosion. Protection against gulley formation on sideslopes is


FINAL SURFACE SLOPED, COVERED & REVEGETATED
SIDE-HILL DIVERSION DITCH
USE OF INHIBITORS WHILE EACH CELL IS ACTIVE.
MAX. 30° SLOPE TO ALLOW COMPACTION & REVEGETATION.
FOUNDATION TREATMENT DEPENDING ON NATURAL CONDITIONS
MATERIAL COMPACTE DURING PLACEMENT
OPTIONAL INTERNAL SEALS TO CREATE CELLS
TOE SEEPAGE COLLECTION
SURFACE DRAINAGE COLLECTION DURING OPERATION

AFTER BELL, 1987

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FIGURE 4-2

CONCEPTUAL CROSS-SECTION OF CELLULAR CONSTRUCTED DUMP particularly critical if the integrity of the cover is to be maintained in areas of intense rainfall or runoff.

Slope protection can be achieved by the use of benches together with the placement of well-graded rip rap or by establishing vegetation on the cover. The latter approach is normally preferred due to cost considerations and the fact that a revegetated dump is aesthetically and environmentally more acceptable in most circumstances. The limitations of vegetation in reducing sulphide oxidation are reviewed in Section 3.1.3, but the objective of seeding cover materials is to stabilize the surface rather than directly influence the oxidation reaction.

The establishment of a compacted and stabilized cover on dump sideslopes normally requires that equipment access to the slopes be feasible. This criterion has a major influence on the dump geometry as it limits the maximum slope between benches to 30 degrees. The effective overall slope, taking into account whatever benches are required to provide access and control surface drainage, is significantly less than this figure, and certainly less than the natural angle of repose to which many dumps have been built in the past. This results in a loss of storage efficiency for the base area of the dump as demonstrated in the comparative figures for a waste dump in the Maritime Provinces (Table 4-2).

TABLE 4-2

Example of the Impact of Dump Geometry on Storage Volume

Dump Geometry	Available Storage Volume (tonnes)	Effective Dump Life (years)
- Maximum side slopes 1:1.4; no benches	15×10^6	24
- Maximum slopes with benches; effective slope 1:1.75	11.8×10^6	20
- 1:3 sideslopes; no benches	5.5×10^6	9
- 1:3 overall (1:2.6 maximum) with benches	7.6×10^6	13

Another problem associated with attempts to cover pyritic waste with a soil cover for revegetation purposes has been the acidification of the cover due to the rise of acid pore water through the cover by capillary action. This has often caused the demise of vegetative covers on reactive tailings several years after an initially successful seeding. The solution is generally recognized to be the placement of a layer of non-reactive granular material between the waste and the growth medium to prevent the capillary action.

It is difficult to predict if this situation will occur in the case of sealed sumps consisting of relatively porous material, but it must be regarded as a potential concern if the waste is of a friable nature and has been compacted to minimize oxygen diffusion. Testing is required to further evaluate this issue.

4.5.4 Existing Dumps

Cellular construction can be applied only to new storage systems. Conventional external covers will often be the only practical mitigative measure, other than leachate treatment, for existing acid waste rock piles. In view of the very limited experience accumulated to date on the long-term performance of waste pile cover systems, it is important that opportunities be identified to apply covers to existing dumps and to monitor their performance over time. In this way, a series of design and maintenance criteria can be established for the future.

4.6 Bactericides and Inhibitors

The use of anionic surfactants, and in particular sodium lauryl sulphate (SLS), has been investigated by the US Bureau of Mines as a bactericide (Kleinmann and Erickson, 1983; Erickson et al., 1985). This and other anionic surfactants are bactericidal towards Thiobacillus ferrooxidans and have been shown to reduce acid formation following their application. This and other substances may be useful to inhibit biological oxidation while revegetation or other more long-term stabilization methods are applied to sulphide wastes.

Other chemicals, such as phosphates, silicates (Watkin and Watkin, 1983), and sodium chloride have also been proposed as inhibitors. Phosphates have been shown to reduce the rate of acid generation. This is attributed to the precipitation of iron phosphates which remove iron as a potential oxidant of pyrite. Other agents, such as silicates and iron hydroxide precipitates, may act as inhibitors by coating the sulphide particles, thereby limiting the access of air. At present, these reagents have been proposed primarily as temporary inhibitors of acid formation to be used as an aid to revegetation efforts.

The use of sodium chloride-rich clays has been proposed as a sealant and bacterial inhibitor for pipeline excavations (Nolan, Davis & Associates, 1984). Sodium chloride has also been applied in association with a clay cover on a pyritic slate waste dump at the Halifax International Airport and the effectiveness of this system is currently being monitored (McCready, 1987).

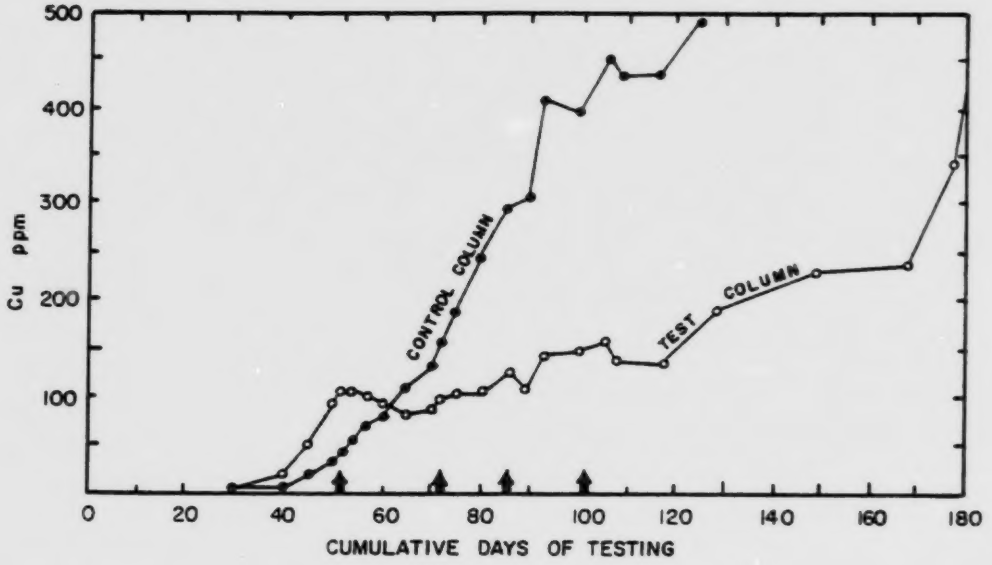
Sodium lauryl sulphate has been used more widely than other reagents as a bactericide in acid drainage situations. Results of laboratory simulations undertaken at Equity Silver (Patterson, 1987a) are shown in Figure 4-3.

When SLS was used in a test column containing pyritic waste, oxidation rates and dissolved metal content were suppressed as compared to an uncontrolled test. Copper was used as a trend indicator, although other metals, sulphates, or acidity values could have been similarly used. After surfactant addition was discontinued, copper values in the test column approached the trend set in the control column, thus indicating re-population of bacterial colonies and acceleration of the oxidation processes.

In actual field trials, it was found to be impossible to saturate the surface of the waste rock throughout the reaction zone and the SLS was rapidly degraded by the effects of temperature and low pH.

In field trials on coal spoils, SLS has been used successfully with the beneficial effects of the bactericide lasting up to six years if applied in the form of rubber matrix pellets, which assure its availability to the receiving environment at controlled rates (Sobec, 1987).

Despite the difficulties experienced to date, it appears that SLS may prove of value for controlling the biological rate of oxidation in base



🡅 SURFACTANT ADDITION

AFTER PATTERSON, 1987

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FIGURE 4-3

EFFECT OF SLS ON OXIDATION RATES

metal waste rock situations as long as it is used in a preventative manner before extreme acid conditions have become established and prior to applying more permanent control measures.

Field trials scheduled for summer 1987 at the Brunswick No. 6 operation will be valuable in providing further practical data on the effectiveness of SLS in acid waste rock situations.

The cost of applying surfactant bactericides such as SLS vary considerably from site to site but are generally in the range of $900 to $1,900 per hectare per application for spray and $6,000 to $10,000 per hectare for combined spray and controlled release pellet applications. These figures are quoted (Restogi and Sobec, 1986) for coal spoil situations but would likely be of similar magnitude for hard rock cases in Canada.

4.7 Other Preventative and Control Methods

This section introduces a number of other potentialpreventative and control methods that were introduced and discussed at the various provincial review meetings (ref. Section 2.1.1).

4.7.1 Anaerobic Disposal

The concept of creating anaerobic conditions in an acid waste rock pile is attractive as it would effectively inhibit the oxidation reaction. This could be achieved by the addition of locally available organic wastes or other material to the dump as it is constructed. Materials which might be considered include muskeg, peat, industrial wastes, sewage sludge, garbage or wood chips. Biodegradation of this material over time would create a reducing environment in the pile thus preventing acid generation. There is, however, a concern that the leachate products from organic decomposition may in themselves prove to be an environmental problem, plus the fact that the organic material would have a finite life, eventually leaving the dump with insufficient reducing capacity to counter the effects of sulphide oxidation.

Further work is required to determine the practicality and long-term effectiveness of this approach. Use of organic materials in association with the cellular method of dump construction described in Section 4.5.2 may, for example, prove advantageous.

4.7.2 Integrated Disposal with Tailings

The review in Part 2 of the report indicates that acid waste rock and tailings are inextricably mixed at many existing sites in Canada, and particularly in Quebec.

Injection of mill tailings into acid waste rock piles was attempted at the Westmin Mine in British Columbia but proved to be impractical. It was considered at the Equity Silver property but never implemented. The objective in each case was to reduce the voids ratio in the waste rock pile so as to minimize air diffusion. The approach was rejected at Equity on the basis that it would introduce a greatly increased reactive surface area into the pile with no assurance that the rate of oxidation would be significantly reduced. One might, therefore, be adding to the acid generation problem in the waste dump where it would be more costly to control than the tailings disposal area.

At the majority of locations where the waste rock is reactive, the mill tailings will also be acid producing. Thus, addition of the tailings to the waste pile, even if technically practical, would seem to be subject to the same risk as that identified at Equity Silver.

Where acid waste rock volumes are small relative to the volume of tailings, there may be advantages in integrating the disposal of all reactive material into a single area; namely, the tailings basin, but again, the practicality of this approach will be very site-specific.

The plan to cover part of the waste rock disposal area with layered tailings at the Westmin Mine in British Columbia (ref. Section 2.1.1) is based on the expectation that the density of the tailings in place will be sufficient to limit the access of air and water, thus controlling the oxidation reaction and/or transport of reaction products through the combined disposal area. The effectiveness of this approach should be monitored. As previously mentioned, the layered deposition technique for mine tailings is effective only in relatively temperate climatic conditions.

4.7.3 Segregation

If the volume of acid waste rock encountered at a mine is relatively small, due for example to its appearing in an isolated area of mineralization, there will be advantages in segregating this material for separate disposal so that the size of the waste pile to which preventative and/or control measures must be applied is kept to a minimum. Segregation of different rock types for various reasons is common practice at many mining operations.

4.7.4 Milling

In many areas, and particularly in Ontario, reactive waste rock is often mineralized. When the long-term cost of managing this material is considered, there may be advantages in putting it through the mill, obtaining some metal recovery and then dealing with the balance as mill tailings.

The economic implications of this approach have not been evaluated and will obviously be very site specific. It is recommended that an evaluation of this approach be made at a number of mines to provide some perspective on its cost and practicality.

If the recoverable minerals are insufficient to offset the cost of milling, there may be advantages in simply crushing the waste for integrated disposal within the tailings area with a view to limiting the number of areas requiring reclamation or controls. Again, this would require site-specific evaluation.

4.7.5 Hydrologic Controls

The isolation of AWR piles from surface and groundwater flows is a fundamental and often very cost-effective measure in controlling acid generation and transport. For example, prevention of flow from a storage pond through the base of a waste pile at the Frood Strobie mine greatly improved the quality and volume of contaminated leachate. A major sidehill drainage diversion will form an integral part of the final configuration of the Equity Silver waste rock dump, thus intercepting surface drainage that would otherwise percolate along the interface of the dump and natural slope.

Isolation of AWR dumps from the groundwater regime is often more difficult than for surface water. Potential concerns over groundwater discharge in the base of the dump must be addressed at the site selection stage, as well as the implications of the potential contaminant plume that might result in the groundwater below the dump. There is no substitute for a thorough hydrogeological characterization of the area at the dump siting and design stage to avoid or minimize these potential concerns. Leachate collection systems have been incorporated into numerous beneficiation heap leach process piles, but this technology has not been extensively applied to waste piles for groundwater protection purposes to date.

4.7.6 Passive Treatment

The point has been made that none of the available or potential methods of managing acid waste rock (with possible exception of underwater disposal) have proven to be totally effective in preventing the formation of contaminated leachate. It is to be hoped that approaches such as cellular dump design, where applicable, will result in sufficiently low levels of leachate that its impact on the environment can be assimilated. Should this not be the case, downstream treatment of the leachate will be necessary.

The RATS Program of Work already includes an assessment of passive treatment for downstream seepage control in relation to sulphide tailings systems (ref. Appendix 2, Projects 4.1 and 5.1). This work will have an equal bearing on the treatment of waste dump seepage.

Passive treatment through the use of wetlands appears to offer some potential. Aquatic plants found in bog systems have a high tolerance to strongly acidic conditions and provide metals removal through uptake and adsorption into the plant tissue. Sulphate reducing bacteria thrive in the anaerobic bottom conditions of the bog and thus provide further metals removal due to microbiological precipitation. A number of wetlands have been established in the eastern US coal regions to provide passive treatment of acid drainage (Pesavento, 1987; Kalin & Everdingen, 1987).

A serious problem with the use of wetlands for passive treatment yet to be adequately addressed, is their ability to provide the necessary level of treatment under peak flow conditions such as the spring runoff, particularly when this is out of phase with the peak growing period for vegetation within the wetland, as is usually the case under Canadian conditions. The effectiveness of wetland systems to handle very high concentrations of metals, as well as their longevity under stressed conditions also need to be evaluated.

4.7.7 Conventional Treatment Systems

At the present time, continuing application of collection and acid drainage treatment is the primary means of controlling contaminated drainage from acid waste rock dumps. The costs of maintaining such systems in perpetuity, as well as the implications of treatment sludge disposal are well recognized. The technology for AMD treatment is well established and described extensively in the literature (e.g. Monenco 1986, Vachon et al., 1987).

The current RATS program of work includes a review of physical and chemical treatment systems that are passive, or have low maintenance requirements and are, therefore, suitable for long-term leachate treatment. This work will have equal bearing on the treatment of waste dump leachates.

4.8 Overview of AWR Management Methods

A number of approaches to managing acid waste rock have been reviewed in the foregoing sections. All these methods are highly site-specific and there is no one approach best suited to all conditions likely to be encountered in the widely ranging mining regions of Canada.

For new systems, underwater disposal and cellular constructed dumps appear to offer the most promise of reducing the rate of oxidation of AWR to acceptable levels. However, these methods, like all others reviewed, have not been evaluated under controlled conditions and the accumulation of experience and performance data in this regard must be priorities in any future work on acid waste rock.

Proper siting and design of AWR management systems is fundamental to reducing their long-term impact and cost of operation.

For existing piles, controls must centre on site-specific combinations of management methods but will normally centre on the placement of a minimum permeability cover to the dump, appropriate protective measures for the cover, diversion of surface and other water throughput, all combined with downstream treatment of contaminated leachate when required. An evaluation of the potential effects of the dump on groundwater quality and movement should also be included. Natural attenuation of the groundwater plume may be acceptable in many circumstances. Rapidly increasing knowledge on the effectiveness of passive treatment systems may reduce the need for ongoing human intervention in the long-term management of rehabilitated AWR dumps in the future.

PART 5

5.0 RESEARCH AND DEVELOPMENT REQUIREMENTS

5.1 Integration With RATS Program

The purpose of this study is to identify the research programs required to integrate acid waste rock into the ongoing Reactive Acid Tailings Program. The stated technical objective of the RATS Program is "to establish techniques that enable the operation and abandonment of acid generating tailings disposal areas in a predictable, affordable, timely, and environmentally acceptable manner."

It is recommended that, with the inclusion of acid waste rock into the Program, the objective should be updated to read "acid generating tailings and waste rock disposal areas."

The following system of merit was developed for the evaluation of proposals for RATS projects and will presumably continue to apply to the expanded program:

1. All projects must relate, at least in large part, and be directed at the agreed-to objective of this program.
2. Generally, the more broadly generic and widely useful the results, the more highly rated will be the project. This does not preclude narrowly applicable programs, but may relegate them to a lower level of importance.
3. The RATS Technical Working Group should be convinced that the proposal is technically worthwhile and has a reasonable probability of succeeding. For this, the proposal must be judged as plausible and beneficial.
4. The cost of the proposal must be appropriate to the benefits expected.
5. Projects with long-term, rather than short-term, and permanent rather than temporary solutions will be favoured.

The research requirements identified with respect to acid waste rock should be consistent with the above program objective and criteria. It is also important to appreciate the basic concept of the Program which is based on a continuing refinement of the primary inputs (i.e. predictive model design, field programs and existing data) leading to the final products of the Program which will consist of a series of "state-of-the-art" manuals and predictive techniques. This concept is shown diagrammatically in Figure 5-1.

Before defining the projects required to address acid waste rock related issues, it is important to assess those projects already in-place or proposed relative to acid generating tailings so as to avoid duplication.

The principal characteristics of current RATS projects are identified in Table 5-1. The full project description sheets are included as Appendix 2.

5.2 AWR Research Requirements

As a result of this study, the following research and monitoring requirements have been identified as necessary to developing an acceptable range of acid waste rock management techniques.

5.2.1 Acid Generation Mechanisms in AWR

a) Comparative evaluation of oxidation mechanisms and rates in AWR as compared to tailings and pit walls.

b) Role of bacteria in promoting sulphide oxidation at near neutral pH's.

c) Role of oxidation by ferric iron and its control.

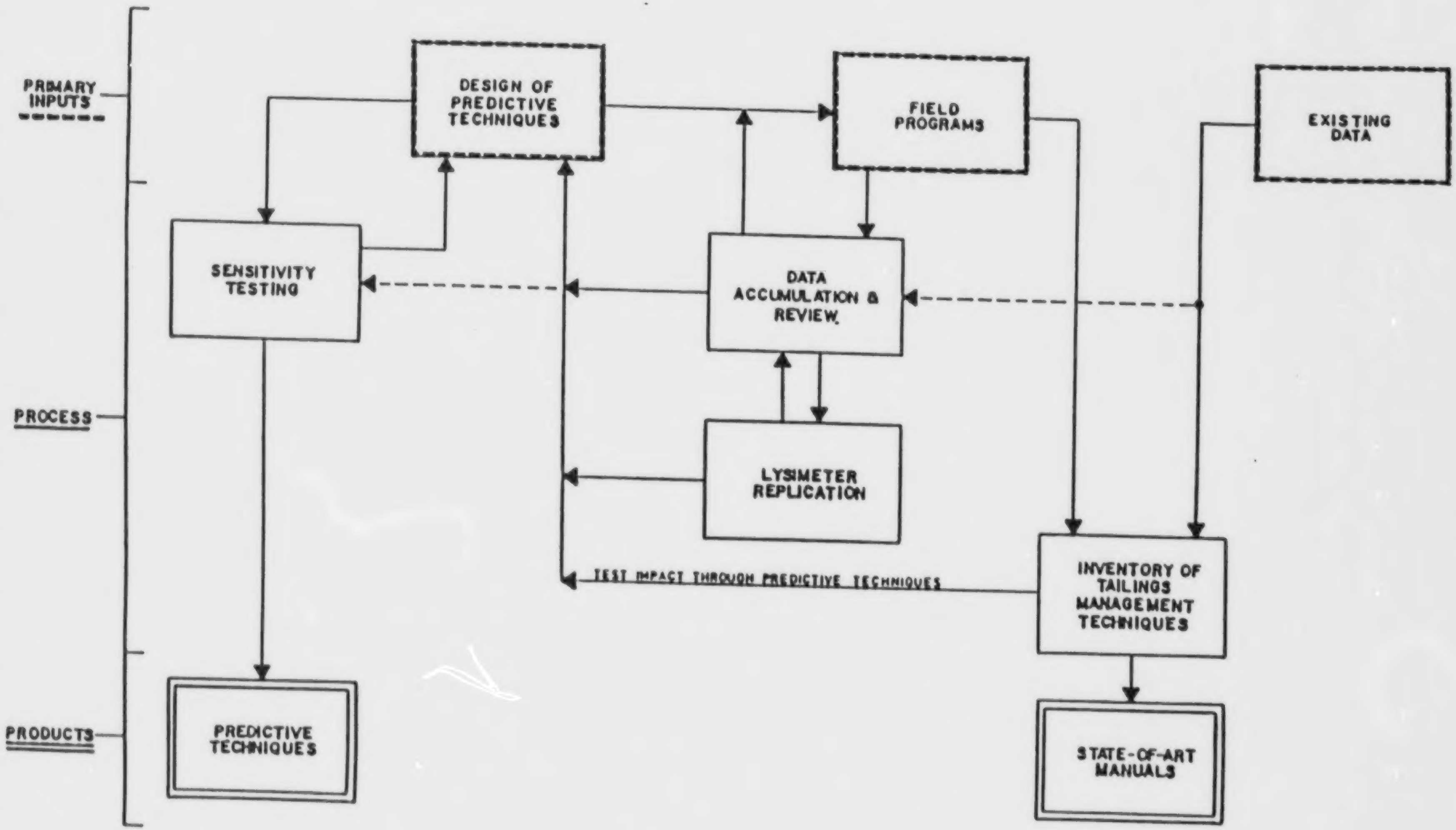
d) Effect of various dump parameters on AWR oxidation including dump dimensions, in-situ voids ratio, particle size gradation, climatic conditions, etc.

e) Relative roles of oxygen diffusion, convection and trapped air in AWR dumps.

f) Bacteriological mechanisms in force as internal temperature of an uncontrolled dump increases.

5.2.2 Predictive Techniques

a) Determination of the relationship between static tests, kinetic tests, and field results including development of recommended predictive practices for AWR.


PRIMARY INPUTS
PROCESS
PRODUCTS
DESIGN OF PREDICTIVE TECHNIQUES
FIELD PROGRAMS
EXISTING DATA
SENSITIVITY TESTING
DATA ACCUMULATION & REVIEW
LYSIMETER REPLICATION
INVENTORY OF TAILINGS MANAGEMENT TECHNIQUES
TEST IMPACT THROUGH PREDICTIVE TECHNIQUES
PREDICTIVE TECHNIQUES
STATE-OF-ART MANUALS

NOLAN, DAVIS & ASSOCIATES

FIGURE 5-1

RATS PROGRAM CONCEPTUAL DESIGN

TABLE 5-1

Summary of RATS Projects
(effective April 1, 1987)

Project No.	Title/Objective	Time Span	Total Budget ($ x 10^3)
1.1	Evaluation of solid covers as oxygen and water barriers on sulphide tailings and the effect of capillary barriers on upward salt migration.	87 - 91	1,250
2.1	Use of water and/or water plus organic covers to prevent oxidation.	87 - 92	490
3.1	Investigation of hardpan formation	87 - 92	600
4.1	Use of wetlands as a downstream passive of treatment system for acidic tailings seepage.	87 - 92	250
5.1	Techniques for downstream passive treatment tailings seepage excluding wetlands.	87 - 91	400
6.1	Definition of the role of vegetation in reactive acid tailings management.	87	30
7.1	State-of-the-art review of tailings impoundment practices.	87 - 89	50
8.1	Review of NUTS work to assess relevance to RATS.	86 - 87	70
9.1	Review of overall literature relevant to RATS.	-	-
10.1	Field procedures manual for RATS evaluations.	86 - 87	30
11.1	Analytical procedures manual.	86 - 87	20
12.1	Reactive tailings quality assurance reference materials.	87 - 88	40
13.1	Development of an evaluation and monitoring manual for RATS projects - application over Program life.	87 - 92	270
14.1	Development of predictive methods for long-term environmental effects.	87 - 89	335
15.1	Evaluation of chemical predictive techniques.	87 - 92	80
16.1	Contingency allowance.	87 - 92	1,450

b) Identification of any differences in chemical predictive techniques for tailings and AWR taking into account the role of particle size differences, diffusivity to air, and geochemical considerations.

c) Development and calibration of a predictive mathematical model for acid generation in waste rock based on application of existing sulphide tailings models.

5.2.3 AWR Management Measures

In-situ Neutralization:

a) Determination of the importance of proximity of sulphide and carbonate sources in achieving in-situ neutralization.

Underwater Disposal:

b) Continuing investigation of the characteristics of existing sulphide tailings deposits underwater as well as tailings maintained in saturated state. Application of findings to AWR.

c) Determination of parameters influencing availability of oxygen to submerged sulphide wastes including diffusion rates, dissolved oxygen, effect of lake turnover.

d) Investigation of the long-term impact of underwater sulphide waste disposal on aquatic organisms, and vice versa.

e) Continuing monitoring of flooded open pits that have been backfilled with AWR.

f) Development of design, construction, and maintenance criteria for man-made wet disposal systems.

Use as Mine Backfill:

g) Development of criteria for the use of AWR as mine backfill.

h) Development of criteria to minimize the oxidation of AWR used for backfill above the water table in open pits.

Sealing Techniques:

i) Definition of the permeability, air diffusivity, and longevity of alternate waste dump cover materials including soils, other naturally available materials, concrete, asphalt, HDPE, and other synthetic covers.

j) Investigation of the acidification of AWR dump covers due to capillary or phreatic contact by dump leachates.

k) Pilot scale construction and monitoring of an experimental cellular AWR dump.

l) Construction and long-term monitoring of several covered AWR piles to determine performance plus design and maintenance criteria.

Bactericides and Inhibitors:

m) Establish criteria for the use of various bactericides and inhibitors on AWR dumps, including surface saturation, dose rates, effectiveness over time, performance differences for fresh and oxidized AWR, etc.

n) Monitoring of the use of NaCl as an inhibitor at Halifax Airport pyritic slate dump.

Other Methods:

o) Evaluation of the cost and practical implications of milling or crushing mineralized waste rock at several sites for ultimate disposal with tailings.

p) Evaluation of the benefits, implications, and practicality of using organic materials such as muskeg, peat, sewage sludge, wood chips, etc., to provide anoxic conditions in AWR dumps.

5.2.4 Treatment/Collection Systems

a) Evaluation of the capabilities of wetlands to provide passive treatment for AWR dump residual leachates, including year-round performance, ability to handle peak flows, etc. Development of design/application criteria.

b) Reviews of mechanical/chemical means of providing long-term passive treatment of residual leachate flows.

c) Review of potential long-term groundwater impacts from AWR disposal systems and the means to minimize these for various foundation conditions.

5.2.5 Overall Planning/Management Considerations

a) Detailed case studies at 4 to 6 operating mines with AWR to determine what approaches to mine development (and specifically AWR management) would be applied if the mine were to be developed at this time with the benefit of current knowledge. This should include definition and costing of site-specific AWR management options, impact on production economics and lifetime costs.

b) Study of the need for institutional controls on future land use at reclaimed mine sites containing acid generating wastes.

5.3 Proposed Program of Research

The approach adopted in defining an initial program of research on AWR which can be integrated into the RATS Program has been to first focus on opportunities provided by already ongoing or proposed work at various mine sites or through other agencies. These opportunities are identified in Column 1 of Table 5-2. The items of research which each will address is also described in the Table along with other known characteristics.

It can be seen from this compilation that a significant program of work directly relating to AWR management has begun to take shape in recent months as a result of various initiatives across the Country. Integration of this work into the RATS Program reporting and review system will provide an excellent base on which to build an integrated program of AWR research.

Major requirements identified in Section 5.2 and not addressed by the projects described in Table 5-2 consist of:

- in-situ neutralization (Item 5.2.3 (a))
- man-made wet disposal systems (Item 5.2.3 (f))
- mine backfill criteria (Items 5.2.3 (g) & (h))
- cellular dump construction (Item 5.2.3 (e))
- groundwater implications (Item 5.2.4 (c))
- planning case studies (5.2.5 (a))
- institutional controls (Item 5.2.5 (b))

TABLE 5-2

Mine Sites, Institutions or Programs Having Actual or Proposed Research Programs Directly Relating to Acid Waste Rock

Ref. No.	Mine Site, Institution or Program Addressing AWR Research	Location	AWR Research Requirement Addressed	Ref. Section in 5.2	Duration	Funding Agency	Approx. Cost ($ x 10^3)	Comments
1	Mount Washington	BC	Select, install and monitor abatement system for AWR pile. Solution will probably entail impervious cover plus d/s passive treatment of residual leachate.	5.2.3 (a) 5.2.3 (1) 5.2.4 (a)	1987 -	Govt. of BC	Not Known	
2	Equity Silver	BC	Montoring effects of side slope sealing on highly reactive side hill dump.	5.2.3 (1)		Equity Silver	Cost of Operation	
			Monitoring effects of backfilling and flooding pit with AWR.	5.2.3 (e)	1986 -			
			AWR test piles.	5.2.3 (1)	1986 -			
3	Pecunis Site (Falconbridge)	ONT	Monitoring long-term effects of applying sewage sludge, garbage, and lime/limestone additives to waste rock cover over pyrrhotite tailings.	5.2.3 (p)	1986-	Falconbridge/ RATS		Already in RATS Program.
4	Fraser Site (Falconbridge)	ONT	Application and monitoring of various chemical applications to AWR.	5.2.3 (a)	1987-	Falconbridge/ RATS		Already in RATS Program.
5	Brunswick No. 6 Mine	NB	Monitoring of controlled bactericide applications.	5.2.3 (m)	1987-1989	BMS		
			Monitoring of backfilling pit with AWR.	5.2.3 (e)	1987-1989	BMS		
6	Heath Steele Site	NB	Characterization of several AWR piles followed by design, implementation and monitoring of appropriate management techniques.	5.2.3 (i) 5.2.3 (1) 5.2.3 (j)	1987-1990	NB MDA/BMS NB Dept. C&T	745	Agreed in principle, contracts currently being negotiated.
7	Halifax International Airport	NS	Observation of long-term effectiveness of NaCl and clay cover applied to acid generating slate pile.	5.2.3 (n)	1987 -	Transport Canada	1,000	Cost includes installation.
8	Nanisivik	NWT	Development, implementation, and monitoring of AWR abandonment	5.2.3 (1)	1987-1992	Nanisivik Mines	Not known	Function of routine

8	Nanisivik	NWT	Development, implementation, and monitoring of AWR abandonment	5.2.3 (1)	1987-1992	Nanisivik Mines	Not known	Function of routine
5	Brunswick No. 6 Mine	NB	Monitoring of controlled bactericide applications.	5.2.3 (m)	1987-1989	BMS		
			Monitoring of backfilling pit with AWR.	5.2.3 (e)	1987-1989	BMS		
6	Heath Steele Site	NB	Characterization of several AWR piles followed by design, implementation and monitoring of appropriate management techniques.	5.2.3 (i) 5.2.3 (1) 5.2.3 (j)	1987-1990	NB MDA/BMS NB Dept. C&T	745	Agreed in principle, contracts currently being negotiated.
7	Halifax International Airport	NS	Observation of long-term effectiveness of NaCl and clay cover applied to acid generating slate pile.	5.2.3 (n)	1987 -	Transport Canada	1,000	Cost includes installation.
8	Nanisivik	NWT	Development, implementation, and monitoring of AWR abandonment measures in Arctic conditions.	5.2.3 (1)	1987-1992	Nanisivik Mines	Not known	Function of routine mine phase-out.
9	Environ. Protection Service, Western Region	BC	Comparison of 3 predictive methods.	5.2.2 (a)	1987 -	Environ. Canada	Not known	Item 9 work will also input to BC Task Force on AWR.
			Comparison of different media for T.ferrooxidans analysis.	5.2.2 (a)	1987 -	Environ. Canada	Not known	
			Compilation of T.ferrooxidans data for BC mines.	5.2.1 (f)	1987 -	Environ. Canada	Not known	
			Evaluation of thermography techniques.		1987 -	Environ. Canada	Not known	
			Detailed evaluation of predictive data and results in BC.	5.2.2 (a) & (b)	1987 -	Environ. Canada	Not known	Longer-term Program will be defined depending on findings.
10	BC Task Force on AWR	BC	3 subgroups currently defining research priorities: - Prediction & Prevention - Treatment & Control - Monitoring		1987 -	Prov. Govt., Industry & MDA Agreement	Not yet defined	Research priorities will be defined in Fall 1987.
11	CANMET - Ottawa	ONT	Various projects on leachability of sulphide ores.	5.2.1	ongoing	CANMET		
			Lysimeter tests on tailings covers.	5.2.3 (i)	ongoing	CANMET		
			Column tests on submerged tailings.	5.2.3 (b)	ongoing	CANMET		
12	Ongoing RATS Programs	various	- Use of water and/or water plus organic covers to prevent oxidation (Project 2.1).	5.2.3 (b)	1987-1992		490	Will be applicable to AWR.
			- Use of wetlands as downstream passive treatment for seepage (Project 4.1).	5.2.4 (a)	1987-1992		250	Should adequately address AWR requirements.
			- Techniques for downstream passive treatment excluding wetlands (Project 5.1).	5.2.4 (b)	1987-1991		400	Should adequately address AWR requirements.
			- Development of chemical predictive methods for long-term environmental effects (Project 14.1).	5.2.2 (a)	1987-1989		335	
			- Evaluation of chemical predictive	5.2.2 (a)	1987-1992		80	

Specific projects will need to be designed and funded to address these requirements. It is assumed that the Technical Working Group of the RATS Program will be responsible for defining and allocating the implementation of this work, which ranges from large-scale field trials in the case of cellular dump construction to "consultant-type" studies in the case of man-made wet disposal systems, mine backfill criteria, groundwater implications, planning case studies, and institutional controls.

In addition to these items, it will be necessary to carefully evaluate each program of research with a view to "rounding out" its scope of work so that other items of importance such as "Acid Generation Mechanisms in AWR" and "Predictive Techniques" which might otherwise be addressed in a somewhat piece-meal fashion, are fully addressed as a function of this program. To achieve this objective, it is recommended that a coordinator be assigned within the Technical Working Group for each of the following:

- Acid Generation Mechanisms in AWR
- Predictive Techniques
- Underwater Disposal
- Sealing Techniques
- Other Management Measures
- Planning

Several of these topics are already being addressed with respect to reactive tailings and therefore need only to be broadened in scope to include AWR.

5.3.1 New Projects

A brief description of the major new projects which need to be established to address the requirements identified earlier in this section is included as a guide to the AWR Subcommittee:

5.3.1.1 In-Situ Neutralization

A laboratory/lysimeter evaluation should be made to determine the importance of the relative distribution of sulphide and carbonate sources in achieving in-situ neutralization in AWR dumps.

Estimated Cost $75,000

5.3.1.2 Man-made Wet Disposal Systems

An engineering evaluation of three mine sites should be carried out to determine the practicality, capital and operating costs, plus long-term safety and maintenance implications, of storing AWR in a man-made wet disposal system applicable to that site. Sites evaluated should include a major open pit operation such as Equity Silver or Gibraltar in Western Canada; an Ontario underground operation with acid development rock; and a New Brunswick operation such as Brunswick No. 6 or Caribou NB.

The study should include the recommendation of design and maintenance criteria to ensure the long-term integrity of these systems.

Estimated Cost $95,000

5.3.1.3 Mine Backfill Criteria

A review of industry experience in using sulphide waste rock as backfill in underground operations leading to the recommendation of criteria for cemented and non-cemented backfill.

Estimated Cost $20,000

5.3.1.4 Cellular Dump Construction

A phased program initially involving an overview study of mining regions in Canada to define where this approach to AWR dump construction is feasible due to the availability of suitable construction materials. This should be followed by actual design, construction, and monitoring of a cellular dump as full or pilot scale evaluation.

Cost of this item will depend largely on whether dump construction at an operating mine can be integrated into the project.

Estimated Cost of Initial Study $65,000

5.3.1.5 Groundwater Implications of AWR Dumps

For this study to be meaningful, it will require actual field data. Thus, timing of the study is best left until several of the waste pile cover evaluation projects (5.2.3 (1)) have been established and thus provide input data without duplication. This project should then consolidate these and other available findings into a review of potential long-term groundwater impacts, mitigative measures, and design criteria.

Estimated Cost of Review Study $60,000

5.3.1.6 Planning Case Studies

Detailed case studies should be undertaken at approximately four operating mines with AWR to determine what approaches to mine development, and specifically AWR management, would be applied if the mine were to be developed at this time with the benefit of current knowledge. This should include the definition and costing of site-specific AWR management options, impact on production economics, and lifetime costs.

This study is felt to be particularly important as it will serve to emphasize the economic implications which AWR management can have on mining operations and, therefore, the importance of developing practical working criteria and management methods.

Estimated Cost is $120,000 for 4 sites assuming cooperative input on operating data from mining operations selected.

5.3.1.7 Institutional Controls

Review of needs and available options for controlling future land use at reclaimed mine sites containing acid generating wastes as well as the institutional means of funding and applying necessary levels of maintenance in perpetuity.

Estimated Cost $30,000

5.4 Overview of AWR Research Requirements

The foregoing identification of AWR research requirements and the recommended approach to implementing these needs results in the following inputs or actions with respect to the Reactive Acid Tailings Program:

1. Endorsement and integration into the RATS Program reporting and review system of the 12 ongoing or proposed programs identified in Table 5-2.
2. Coordination of AWR research needs with those relating to reactive tailings in each of the following areas:
    - Acid Generation Mechanisms in AWR
    - Predictive Techniques
    - Underwater Disposal

- Sealing Techniques
- Other Management Measures
- Planning

3. Funding and implementation of the seven specific projects described in Section 5.3.1. The total cost of these programs is estimated to be in the order of $465,000 assuming that construction costs are adsorbed as operational expenditures at participating mines.

   This represents the value of projects which will require direct funding from the RATS Program and is incremental to the benefits that will be derived from other related projects described in Item 1 (i.e. Table 5-2).

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APPENDIX A

NOLAN, DAVIS & ASSOCIATES

ACID WASTE ROCK MANAGEMENT STUDY

Place: Hemlock Room
Parliament Buildings
Victoria, British Columbia

February 24, 1987
9:00 a.m.

Present: A.V. Bell; Nolan, Davis & Associates
John Errington; B.C. Ministry of Energy, Mines and Petro. Res.
Ron Hillis, Utah Mines Ltd.
Jake McDonald, Mining Association of British Columbia
David Parsons; B.C. Ministry of Environment
Robert Patterson, Equity Silver Mines Ltd.
John Dick; B.C. Ministry of Envir., Planning & Assessment Br.
Bob Dawson; B.C. Ministry of Envir., Waste Management Br.
Ruben Schurr, B.C. Ministry of Envir., Waste Management Br.
Vic Dawson; B.C. Ministry of Energy, Mines & Petroleum, Victoria
Murray Galbraith; B.C. Min. of Energy, Mines & Petro., Victoria
Roy John; Dept. of Energy, Mines and Resources, Ottawa
Keith Ferguson; Environment Canada, Vancouver

AGENDA

1. Introductions

2. Project Outline and Perspective (A.V. Bell)

3. Status of any recent legislation or policies in province relevant to waste rock

4. Study Information Requirements - Review and Discussion as per attached sheet

5. Agreed action

6. Any other matters

MEETING NOTES

A.V. Bell reviewed Items 1 and 2 on the Agenda.

Item 3:

At the exploration Phase. approvals must be obtained from the Chief Inspector under the Mines Act. These address reclamation requirements as applicable. Once a mine approaches a development decision, a prospectus must be filed with the review committee of the British Columbia Mine Development Review Process. This is reviewed and a recommendation made to the Environment and Land Use Committee. This group will issue an approval in principal, after which the developers can apply for regulatory approvals under the Mines Act. This includes a separate approval and permit for the reclamation program. Input is required from all other interested agencies. A bond must be posted.

Water quality objectives are currently being established and will be used to judge the effectiveness of abandonment procedures prior to a reclamation bond being released.

Item 4:

John Errington tabled a list of operating and abandoned mines with acid drainage in British Columbia (see attached).

The ten properties listed were reviewed as follows:

1. **Gibraltar Mine:** This is a large, open pit copper mine, operated by Placer. It was regarded as a potential acid consumer but five to six years ago elevated SO_4 levels were observed from one of the waste dumps. Leachate was low pH, high in copper, but relatively low in iron. The company built a collection pumping system, combined drainage with alkaline tailings and discharged into tailings pond. Test work was undertaken on bioleaching. Six months ago the company started spraying sulphuric acid on No. 3 dump in order to leach copper. It is hoped that this will remove sulphides but there is a concern that alkalinity will also be removed and the entire dump will become a long-term acid producer. Plans are currently being formulated to leach No. 1 dump.

2. **Equity Silver:** This is a large open pit silver mine at relatively high elevation. Consultants predicted that acid-generation would not be a problem due to unfavorable climatic conditions. Site now produces one million cubic meters of AMD annually. Waste rock dump is a major issue. Temperature probes are now recording 55°C temperature in the pile and little improvement in temperature readings has been observed as a result of the one meter till cover placed on the side slopes.

This cover has not been compacted. Thermophillic bacteria must be active in the pile at these temperatures.

Placement of waste rock in the flooded South-Tail pit has been successful in preventing acid-generation, although zinc levels are slightly above standard.

Waste rock test plots have been established to check the effectiveness of different covers but are now felt to be of too small a size (approximately 15 tons). Sludge from the treatment plant has been classified as a "special waste" by the British Columbia environment. The company is preparing a detailed abandonment plan to be completed by October 1988.

3. **Westmin:** Has been in operation since 1967. Major new reserves were delineated four years ago and the property now has a 30 year life projection. Open pit and underground operations. Tailings were originally discharged into Buttle Lake, which drains into the Campbell River System (major salmon stream). Metal levels in the Campbell River were found to be increasing and the company was ordered to stop the discharge of tailings into the lake. It was subsequently determined, however, that the problems were not due to the subaqueous tailings disposal but due to the leaching from a waste rock dump. This leachate has since been collected by a toe collection ditch and the problem is controlled. Subsequent test work on the tailings in Buttle Lake indicate no acid-generation or other associated contamination problems.

Tailings are now discharged into a land-based disposal area, using the layered discharge technique. This produces an unsaturated, high density deposit but it is still unknown as to whether it will become acid-generating. Westmin has experimented with the injection of tailings into the waste rock piles with a view to reducing the voids ratio and has also tried injection of treatment sludge but was unable to maintain the sludge in the pile. Patterson advised that column tests of sludge injection into waste rock, conducted at Equity showed positive results until the alkalinity in the sludge was depleted, after which the acid production potential of the column became far worse than the pre-sludge injection condition.

Westmin plans to extend the tailings area back over the waste rock disposal area such that it be partially covered by layered tailings deposition.

4. **Noranda Bell:** This is an open pit operation which produces acid on a seasonal basis. The waste rock has been used for tailing dam construction and results in acid seepage. This is collected in seepage recovery ponds and pumped back to the tailings system. The concern is how to maintain the control after active operations cease in two to three years. It was felt to be likely that a seepage recovery system will be required for many years.

5. **Sullivan Mine:** The main concern at Sullivan is primarily associated with tailings but there is some waste rock resulting from underground development. Contaminated leachate from this area is collected and treated with other site drainage.

6. **Brittania:** Primarily an underground operation but an open-pit resulted from mining of the crown. The mine is no longer operated but coastal disposal of tailings and untreated acid drainage have been concerns associated with the property.

7. **Duthie:** This is an abandoned property at which acid generating tailings were discharged into a local stream system. No waste rock.

8. **Anyox:** An abandoned property in which waste rock was used for construction of a rail line. There are no dumps. High copper levels have been observed in a local creek.

9. **Mount Washington:** The government is currently undertaking an acid mine drainage abatement study at this property. A relatively small acid waste rock dump results in high acidity and metals drainage impacting on local salmon streams during the period of spring snow melt and runoff. A number of abatement options have been reviewed by consultants (Steffan Robertson & Kirston) and the government may proceed with an abatement program at this site. The consultant report is not available for release at this time.

10. **Tulsequah:** The problem at this site is primarily one of contaminated mine water escaping from abandoned underground workings, although there is some waste rock at the site.

Management Strategies:

Alternate management strategies for waste rock were discussed as follows:

1. **Insitu Neutralization:** J. Errington felt that this represents the primary tool for future control of acid wastes. Blending of wastes to result in a net acid consumptive blend is a key method if the site has calcareous materials as well as acid. This approach has been used with success at the Quinsam Coal Property in British Columbia. The need for accurate prediction and identification techniques were stressed as being key to this approach.

2. **Underwater Disposal:** There are five major mine sites in British Columbia at which underwater disposal of mining waste has been practiced. It was felt that a systematic review of these sites would be valuable. Generally agreed that underwater disposal of acid waste is technically desirable but often subject to negative political and public pressures.

Use of manmade disposal areas in which waste rock or tailings could be maintained in a saturated condition in perpetuity was discussed and agreed to be desirable as long as fluctuating water levels within the waste could be avoided.

3. **Use as Mine Backfill:** Westmin propose to move their No. 1 dump underground as part of their ultimate reclamation plan. They currently use tailings for mine backfill. The Sullivan Mine used pyrrhotite as backfill, which resulted in a widespread exothermic reaction, almost resulting in the loss of the mine.

4. **Sealing Techniques:** The function of waste rock covers was reviewed and it was agreed that a till cover, such as at Equity, would provide control of air induction to the pile; however, it was pointed out by Roy John that to achieve control of diffusion, a cover must reduce oxygen levels to 0.05 percent and that this had not been achieved on tailings areas such as Waite Amulet.

    It was reported that Westmin has evaluated a number of membranes for covering waste rock areas. The previously mentioned study on the Mount Washington property also evaluated this alternative.

    Mechanical covers such as asphalt or concrete were not regarded favorably by those present due to the requirement for maintenance and tendency to degrade with frost action etc.

    Definition of the ultimate land use was felt to be a key issue as institutional control of reclaimed acid generating waste sites will be a prerequisite.

5. **Bactericides:** Bob Patterson reported that applications of SLS at Equity Silver cost in the order of $300 per acre and worked if you could get the solution throughout the pile. SLS breaks down in low pH conditions, however. John Dick reported the availability of a review paper on bactericides and will forward a copy to A.V. Bell.

6. **Anaerobic Disposal:** Concern was expressed that this would not represent a long-term solution, as decomposition of organic material would occur over a relatively short time frame, as compared to the potential for acid-generation.

7. **Passive Controls:** Use of wet lands downstream of acid-generating waste rock piles was reviewed. Keith Ferguson reported some work undertaken at Mount Washington but expressed the concern that growth in the wet land did not coincide with the period of maximum runoff. The swamp area below the Equity Silver property is thought to provide significant effluent polishing capability.

Ranking of Research Requirements:

It was agreed that further development of prediction/modelling techniques is the highest priority research requirement. Further study of sealing techniques and a broad review of the underwater disposal option, including man-made underwater systems, were felt to be the second and third ranking priorities, respectively.

Potential Research:

A number of research projects relevant to British Columbia were identified:

1. Study of the five existing underwater disposal areas for long-term effects. Recommendation that the work undertaken by Pederson and Calbert, of UBC Department of Oceanography be continued. They have been particularly looking at the quality of interstitial water associated with existing underwater waste disposal at Rupert Inlet and Buttle Lake.

2. Any work undertaken at the Mount Washington site should be reviewed and monitored as this constitutes an ideal test site due to its relatively small size and availability of good baseline data.

3. Equity Silver - Monitoring of the effects of the Waste Rock Dump Cover program and temperature instrumentation should be maintained.

4. The Gibraltar Leach Project should be monitored in order to determine whether enhanced leaching is likely to improve the quality of leachate from a waste pile over an extended time-frame.

5. Kutcho Mine - This is a property currently being developed by Esso at which the standard predictive tests are less than conclusive. Monitoring of actual site conditions as they develop will therefore provide further insight into predictive techniques.

6. Roy John reported on the availability of predictive modelling developed under the NUT Program. The acid-generating aspects of this model have been segregated and, although not in a user-friendly format at this time, can be made available to interested parties. CANMET hopes to convert the model to a user friendly package and, if funds are available, to investigate its applicability to waste rock as compared to tailings.

Item 5:

John Dick will forward a copy of the paper reviewing bactericide characteristics to A.V. Bell.

Item 6:

Ron Hillis reported that waste rock is regarded as a very high priority by the mining industry and regulatory agencies in British Columbia. They have a technical working group and steering committee set up paralleling the RATS organization on the national level. There is a concern in British Columbia that the problem cannot wait the five year time frame of the national RATS Program.

British Columbia has placed funding for acid mine drainage research as a high priority in its submission to the Canadian Council of Resource Ministers, relative to cooperative funding.

There was no other business and the meeting adjourned at 12:45 p.m.

cc: To all present

EXAMPLES OF SOME ACID MINE DRAINAGE IN BRITISH COLUMBIA

(Adapted from Ferguson and Mehling, 1986)

OPERATING MINES

MINE	LOCATION	SOURCE AND PEAK CONTAMINANT CONCENTRATIONS* mg/l			
		Underground Mine	Open Pit	Tailings	Waste Rock
Gibraltar	McLeese Lake				pH-3.1 acid-2675 Cu-257 Al-183 Fe-71
Equity Silver	Houston		pH-3.0 acid-364 Cu-17.5 Zn-9.9		pH-2.4 acid-44100 Cu-791 Zn-350
Westmin	Myra Falls	pH-6.9 acid-61 Zn-37 Cu-4 Al-5 Fe-16	pH-3.0 acid-423 Zn-51 Cu-10 Al-20 Fe-72		pH-3.8 acid-397 Zn-74 Cu-13 Al-36 Fe-9.5
Noranda (Bell)	Granisle		pH-6.9 acid-26 Cu-0.8		pH-3.3 acid-185 Cu-10.6 Fe-36.7
Sullivan	Kimberley	pH-3.1 acid-4280 Zn-69 Fe-191 Mn-25 Al-88 Pb-6.4		pH-2.7 acid-995 Zn-76 Fe-817 Mn-44 Al-71 Pb-5.3	

$CaCO_3$ mg/l

CONTINUED . . . .

TABLE 4

EXAMPLES OF SOME ACID MINE DRAINAGE IN BRITISH COLUMBIA

(Adapted from Ferguson and Mehling, 1986)

ABANDONED MINES

MINE	LOCATION	SOURCE AND PEAK CONTAMINANT CONCENTRATIONS*			
		Underground Mine	Open Pit	Tailings	Waste Rock
Britannia	Britannia Beach	pH-2.7 acid-494 Cu-43 Zn-32 Fe-45			
Duthie	Smithers			pH-1.9 acid-N.A. Cu-138 As-5060 Zn-1360 Fe-13300	
Anyox	Anyox	pH-N.A. acid-N.A. Cu-1.7 Zn-3.4 Al-37 Fe-195		pH-N.A. acid-N.A. Cu-3.1 Zn-5.9 Al-150 Fe-1650	pH-N.A. acid-N.A. Cu-2.17 Zn-3.74 Al-45.6
Mt. Washington	Courtenay				pH-3.4 acid-431 Cu-77 Al-50 Fe-7.2
Tulsequah	Taku River	pH-5.7 acid-43 Cu-2.97 Zn-14.1 Fe-0.4			

NOLAN, DAVIS & ASSOCIATES

ACID WASTE ROCK MANAGEMENT STUDY

Place: Manitoba Dept. of Mines & Energy
550 - 330 Graham Ave.
Winnipeg, Manitoba

February 26, 1987
1:30 p.m.

Present: A.V. Bell; Nolan, Davis & Associates
Al Beck; Envir. and Workplace, Safety & Health, Envir. Management
Clem Moche; Environmental Management, Manitoba
Sobharam Singh; Energy and Mines, Manitoba
Bill Bardswick; Energy and Mines, Manitoba
J.S. Ashton; Inco Ltd., Manitoba Division
Dave Cook; Energy and Mines, Manitoba
Ray Band; Falconbridge Ltd., Winnipeg

AGENDA

1. Introductions
2. Project Outline and Perspective (A.V. Bell)
3. Status of any recent legislation or policies in province relevant to waste rock
4. Study Information Requirements - Review and Discussion as per attached sheet
5. Agreed action
6. Any other matters

MEETING NOTES

A.V. Bell reviewed Items 1 and 2 on the Agenda.

Item 3:

Reclamation plans must be filed with the Clean Environment Commission, who will issue a permit after the application has been reviewed as satisfactory by the Department of Environment and by Mines Branch. The permit is issued under the authority of the Clean Environment Act. Bonding has been required only for the Fox Mine.

Item 4:

Dave Cook tabled a listing of past and present copper-zinc mines in Manitoba (attached) and advised that only seven (7) pits have operated (still in operation) in the province. Waste rock situations in the province were reviewed as follows:

1. **FlinFlon:** Waste is being used for road construction etc. with no acid-generation problem identified to date.
2. **Rattan Mine:** This property represents the largest volume of waste rock in Manitoba. All waste piles drain into the tailings area. No data exists as to their volume or leachate quality.
3. **Dickson Mine:** Underground operation at which there was a fire due to sulfide emmission. May be some waste rock on the property.
4. **Pipe Mine:** Open pit and underground operation for nickel. Operated by Inco. Significant waste volumes but appear to be acid-consuming. The open pit has been closed and the underground operation is currently inactive.
5. **Thompson Mine:** Active open pit, nickel operation. 1.7 million tonnes of waste rock. 40 percent used for road dressing. Thought to be acid-consuming. No acid-generation tests todate.
6. **Maskwa:** Open pit, nickel/copper operation (Falconbridge). Thought to be very little sulphide in waste rock.
7. **Dunbarton:** Underground operation. Very little waste rock on surface.
8. **Manibridge:** As above.
9. **Don-Jon:** Underground, copper/zinc operation with some development rock on surface. Thought to be acid-generating but small volume. Only 87,000 tons of ore mined.

Summary:

Acid-generating waste rock is not regarded as a major issue in Manitoba. Although most ores are highly sulphidic, the waste rock associated with open pit operations appears to be generally lacking in sulphides or is well buffered in the majority of cases.

Management Strategies:

The following alternate management strategies were reviewed by A.V. Bell:

- insitu neutralization
- underwater disposal/flooding
- use as mine backfill
- sealing techniques
- use of bactericides
- creation of anaerobic disposal conditions

Those present were interested in experiences elsewhere but had not had occasion to consider these options relative to Manitoba mines.

Ranking of Research Requirements:

Improvement of current prediction capabilities was felt to be a leading priority.

No sites were identified as being particularly appropriate for research purposes in the province.

Item 5:

No further action was identified.

Item 6:

No other business. Meeting adjourned at 3:30 p.m.

cc: Those present
Roy John, CANMET

Name of Mine	Operator (Abbrev.)	Area	Locality on Figure 1	Operation Starting Date	Closure Date	Tonnage mined up to Dec. 1984 TONNES			Ore Reserves as of Dec. 31, 1984 TONNES			Production in 1984 TONNES		
							%Cu	%Zn		%Cu	%Zn		%Cu	%Zn
Mandy	Tonopah Mining Co.	Flin Flon area	1	1916	1919	22 885	20.18							
Flin Flon	H.B.M.&S.[1]	Flin Flon	1	1930		61 009 239[1]	2.19	4.2	1 377 495[1]	1.91	1.0	480 760[1]	1.54	2.0
Sherridon	Sherritt Gordon	70 km NE of Flin Flon	2	1931	1932	7 747 996	2.47	2.00						
Sherridon	Sherritt Gordon	70 km NE of Flin Flon	2	1937	1951									
Mandy	Emergency Metals Ltd.	Flin Flon area	1	1943	1944	102 231	5.61	13.95						
Cuprus	H.B.M.&S.	Flin Flon area	1	1948	1954	462 102	3.24	6.42						
Schist Lake	H.B.M.&S.	Flin Flon area	1	1954	1976	1 877 883	4.21	7.00						
North Star	H.B.M.&S.	Flin Flon area	1	1955	1958	241 643	6.11							
Don Jon	H.B.M.&S.	Flin Flon area	1	1955	1957	79 313	1.07							
Chisel Lake	H.B.M.&S.	Snow Lake area	3	1960		5 061 070	0.60	10.98	2 238 757	0.32	9.5	190 409	0.42	7.0
Rod No. 1	Stall Lake Mines Ltd.	Snow Lake area	3	1962	1964	22 675	5.00	4.5						
Stall Lake	H.B.M.&S.	Snow Lake area	3	1964		3 158 086	4.29	0.57	2 105 663	4.42	0.3	249 174	4.11	0.5
Osborne Lake	H.B.M.&S.	Snow Lake area	3	1968	1983	2 952 007	3.33	1.52	528 054	2.45	1.29			
Fox[2]	Sherritt Gordon	40 km SW of Lynn Lake	4	1970		11 210 539	1.81	1.77	631 401	N.A.	N.A.	663 152	1.62	2.20
Anderson Lake	H.B.M.&S.	Snow Lake area	3	1970		2 193 546	3.41	0.1	996 055	3.54	0.1	168 691	3.51	0.1

TABLE 2 PAST & PRESENT COPPER ZINC MINES IN MANITOBA (Cont)

Name of Mine	Operator (Abbrev.)	Area	Locality on Figure 1	Operation Starting Date	Closure Date	Tonnage mined up to Dec. 1984 TONNES			Ore Reserves as of Dec. 31, 1984 TONNES			Production in 1984 TONNES		
							%Cu	%Zn		%Cu	%Zn		%Cu	%Zn
Dickstone	H.B.M.&S.	Snow Lake area	5	1970	1975	775 210	2.47	3.13	308 300	2.36	4.0			
White Lake	H.B.M.&S.	Flin Flon area	1	1972	1983	889 728	1.97	4.63						
Ghost Lake & Lost Lake	H.B.M.&S.	Snow Lake area	3	1972		478 277	1.38	8.87	127 413	1.02	7.5	40 743	1.11	1.9
Ruttan	Sherritt Gordon	90 km SE of Lynn Lake	6	1973		21 940 440	1.23	1.50	19 321 226	1.46	1.3	1 411 194	1.37	0.91
Centennial	H.B.M.&S.	Flin Flon area	1	1977	1984	1 012 818	1.32	2.31	1 351 113	1.48	2.0			
Westarm	H.B.M.&S.	Flin Flon area	1	1978		1 063 861	1.38	1.25	525 542	1.54	1.8	122 952	1.80	1.1
Spruce Point	H.B.M.&S.	Reed Lake	7	1982		328 774	2.64	1.50	1 164 588	2.20	1.7	169 934	2.60	2.9
Trout Lake	H.B.M.&S.	Flin Flon area	1	1982		1 054 018	2.00	4.36	3 196 413	2.33	5.5	517 461	2.35	3.8
Rod No. 2[3]	H.B.M.&S.	Snow Lake area	3	1984		42 621	6.39	2.2	602 806	6.13	2.9	42 621	6.39	2.2

H.B.M.&S. — Hudson Bay Mining & Smelting Co., Limited

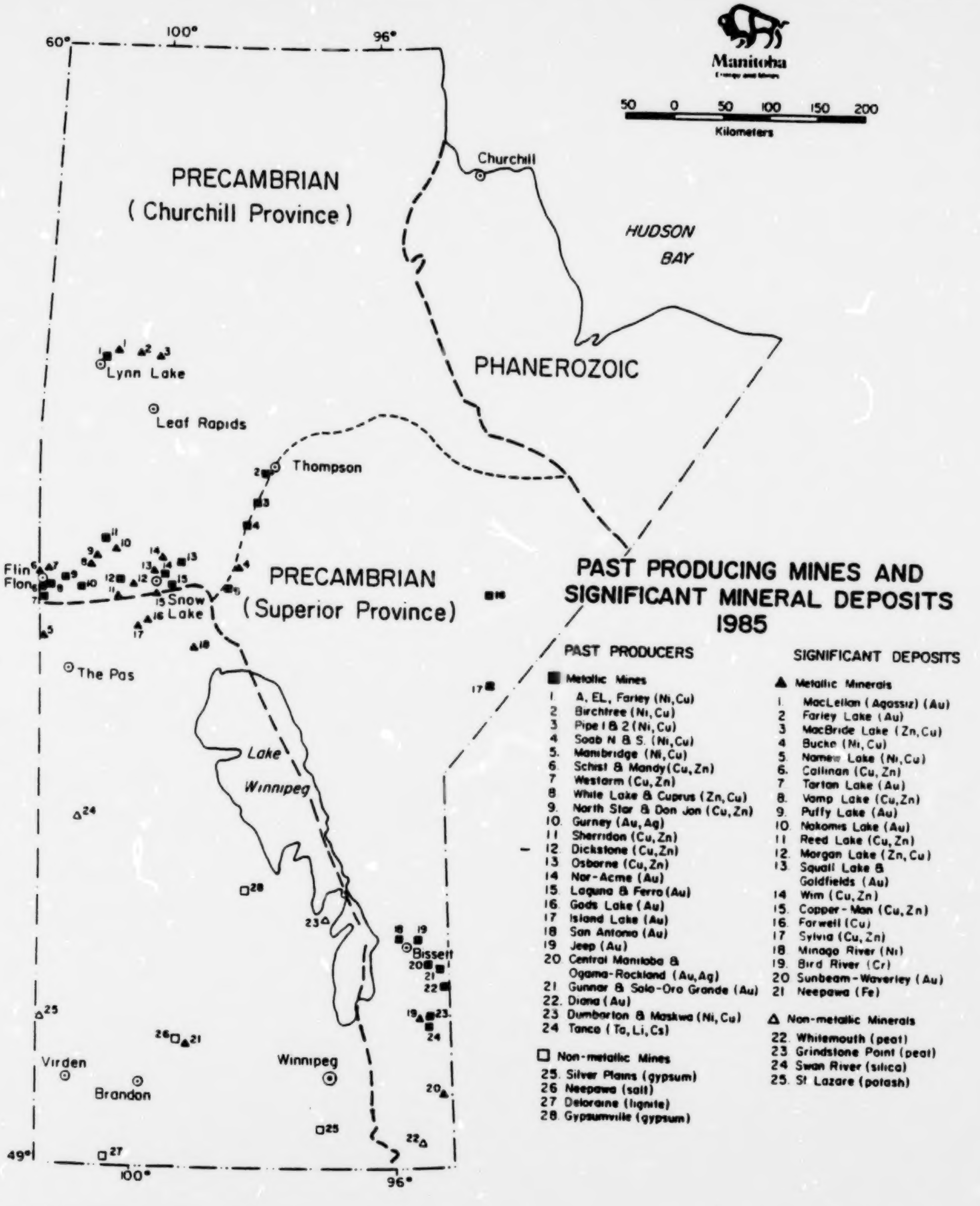
[1] Include the Saskatchewan portion of the Flin Flon deposit

[2] The Fox Mine is scheduled to be closed in late 1985

[3] Production was resumed in 1985

NOTE DOES NOT INCLUDE NICKEL

From: Manitoba Energy and Mines Publication: 'Copper and Zinc in Manitoba'


Manitoba
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50 0 50 100 150 200
Kilometers
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PRECAMBRIAN
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Churchill
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PHANEROZOIC
Lynn Lake
Leaf Rapids
Thompson
Flin Flon
Snow Lake
PRECAMBRIAN
(Superior Province)
The Pas
Lake
Winnipeg
Bissett
Virden
Brandon
Winnipeg
49°
100°
96°

PAST PRODUCING MINES AND SIGNIFICANT MINERAL DEPOSITS 1985

PAST PRODUCERS

■ Metallic Mines

1. A, EL, Farley (Ni,Cu)
2. Birchtree (Ni,Cu)
3. Pipe I & 2 (Ni,Cu)
4. Soab N & S. (Ni,Cu)
5. Manibridge (Ni,Cu)
6. Schist & Mandy (Cu,Zn)
7. Westarm (Cu,Zn)
8. White Lake & Cuprus (Zn,Cu)
9. North Star & Don Jon (Cu,Zn)
10. Gurney (Au,Ag)
11. Sherridon (Cu,Zn)
12. Dickstone (Cu,Zn)
13. Osborne (Cu,Zn)
14. Nor-Acme (Au)
15. Laguna & Ferro (Au)
16. Gods Lake (Au)
17. Island Lake (Au)
18. San Antonio (Au)
19. Jeep (Au)
20. Central Manitoba & Ogama-Rockland (Au,Ag)
21. Gunnar & Solo-Oro Grande (Au)
22. Diana (Au)
23. Dumbarton & Maskwa (Ni,Cu)
24. Tanco (Ta,Li,Cs)

☐ Non-metallic Mines

25. Silver Plains (gypsum)
26. Neepawa (salt)
27. Deloraine (lignite)
28. Gypsumville (gypsum)

SIGNIFICANT DEPOSITS

▲ Metallic Minerals

1. MacLellan (Agassiz) (Au)
2. Farley Lake (Au)
3. MacBride Lake (Zn,Cu)
4. Bucko (Ni,Cu)
5. Namew Lake (Ni,Cu)
6. Callinan (Cu,Zn)
7. Tartan Lake (Au)
8. Vamp Lake (Cu,Zn)
9. Puffy Lake (Au)
10. Nokomis Lake (Au)
11. Reed Lake (Cu,Zn)
12. Morgan Lake (Zn,Cu)
13. Squall Lake & Goldfields (Au)
14. Wim (Cu,Zn)
15. Copper-Man (Cu,Zn)
16. Farwell (Cu)
17. Sylvia (Cu,Zn)
18. Minago River (Ni)
19. Bird River (Cr)
20. Sunbeam-Waverley (Au)
21. Neepawa (Fe)

△ Non-metallic Minerals

22. Whitemouth (peat)
23. Grindstone Point (peat)
24. Swan River (silica)
25. St Lazare (potash)

Provided by Exploration Services Section, Mines Branch, Manitoba Department of Mines and Energy.

NOLAN, DAVIS & ASSOCIATES

ACID WASTE ROCK MANAGEMENT STUDY

Place: Ontario Mining Association
111 Richmond Street
Toronto, Ontario

March 11, 1987
9:00 a.m.

Present: A.V. Bell; Nolan, Davis & Associates
Bob Garrett; Sherman Mine
Pat Bolger; Inco Limited
John Hawley; Ministry of Environment
Charles Ferguson; Inco
Maxine Wiber; Noranda Inc.

AGENDA

1. Introductions
2. Project Outline and Perspective (A.V. Bell)
3. Status of any recent legislation or policies in province relevant to waste rock
4. Study Information Requirements - Review and Discussion as per attached sheet
5. Agreed action
6. Any other matters

Toronto, Ontario **March 11, 1987**

MEETING NOTES

A.V. Bell reviewed Items 1 and 2 on the Agenda.

Item 3:

At the present time, mining approvals are dealt with on a case by case consultative basis with the regulatory agencies. New mining operations have to document a complete project life profile, including abandonment plans.

The regulatory process is currently very much under the influence of a newly introduced program, referred to as the "Municipal and Industrial Strategy for Abatement" (MISA). This will place the emphasis of regulatory controls on meeting effluent criteria, which will be enforced by an environmental police force, with executive jail sentences and fines of up to $200,000 per parameter per day for noncompliant discharges. The program will have a major influence on the interrelationship between government and industry, particularly with respect to cooperative programs, exchange of data, etc.

Item 4:

John Hawley is currently preparing a listing of mining and environmental issues as part of the MISA program. This will be available April 3, 1987, and a copy will be forwarded to A.V. Bell.

The following properties were identified as being of primary importance relative to acid-generating waste rock in Ontario:

1. **Kidd Creek:** This was initially developed as an open pit operation but is now underground. All effluents are directed to a treatment plant so there is no external impact. The majority of the waste rock is in fact low grade ore and is being fed to the mill on a regular basis.

2. **Frood Stobie:** Development began before turn of century. Open pit/underground operation owned by Inco. Many sulphide waste piles associated with the operation, with two being of particular concern. Inco are under pressure from Ministry of Environment to develop long-term management strategies. Have tried covering one pile with lime. Quality of leachate from the second pile has been improved by preventing flow from a storage pond through the base of the pile.

3. **Murray Clarabelle Mine:** An Inco operation near Copper Cliff, developed at the turn of the century. Large volumes of waste rock but drainage controlled by regional collection and treatment system. No reclamation measures considered to date other than use of the rock as backfill.

4. **Creighton Mines:** An old open pit/underground operation, begun prior to turn of century. Waste rock used for construction over widespread area. Drainage controlled by regional collection/treatment system. No reclamation measures considered to date.

5. **Garson Mine:** Old underground mine started pre-1900 with recent open pit operation. Volumes of leachate from waste rock pile very small relative to other areas. Regarded as a minor problem.

6. **Levack:** Underground operation developed at the turn of the century by Inco. Some development rock used for construction around the area.

Pat Bolger will provide estimated tonnages for the above Inco operations.

7. **Falconbridge Operations:** Bob Michelutti was expected to be at the meeting and he agreed to provide description of Falconbridge Properties. (Appended)

8. **Sherman Mine:** This is a silicate iron formation being mined by open pit. One face of the pit consists of graphite sulphide mineralization, which is very reactive and results in AMD plus reactive waste rock. A number of management options have been considered, including: separate disposal areas, disposal and flooding in pit, and disposal in the tailings area. The tailings basin has been the primary disposal method to date. Tailings themselves are not reactive and are used to cover the waste rock. Management situation is complicated by the fact that the pits are owned by several different lease holders and there is no agreement to use the pits for waste disposal.

May be able to use locally available bark as an organic/cover for the tailings. Have experimented with muskeg as a cap for the waste dumps but do not feel that this will constitute a walk away solution.

Bob Garrett will provide a review of alternative reclamation strategies prepared for the property.

9. **Mattabi Mines:** Operated by Noranda. Started as an open pit and went underground. Mine will soon be closed but mill will continue to operate to treat Lyon Lake ore. Large volumes of waste rock associated with property including:

- overburden waste rock pile in excess of 1 million tonnes (160 acres)
- gossan pile 200,000 tonnes
- waste copper pile - 500,000 tonnes

Reclamation plan will address possibility of moving gossan and waste copper piles into open pit. Collection and treatment system in place for the overburden pile.

10. **Lyon Lake Mine:** This is an active underground property, operated by Noranda. Primary issue is acid mine water rather than waste rock.

11. **F. Group Mine:** Small open pit operation now completed. Acid drainage from a small sulphide waste pile is diverted into open pit and treated seasonally by drawing down the level through lime neutralization plant.

12. **Geco Mine:** Started as open pit but now underground. Waste rock used extensively around site but drainage collected and treated so not regarded as an external problem, although implications of closure are significant.

13. **Kam Kotia Mine:** This is an abandoned property now controlled by the Crown. Although there are considerable volumes of sulphide waste rock at the site, the primary issue is regarded as one of acid tailings management. Although Kam Kotia is the most notable, there are probably 200 similar properties where acid waste rock tailings are associated with abandoned sites. Although these sites are a concern, the waste rock aspects are not regarded as a priority in themselves.

Management Strategies:

Alternate management strategies for waste rock were discussed as follows:

1. **Insitu Neutralization:** Generally regarded as impractical, on the basis of cost and volume of neutralizing material required. Ministry of Environment evaluated cost of mixing neutralizing reagents with tailings at Elliot Lake with a view to providing long-term neutralizing capacity but cost was totally prohibited.

2. **Underwater Disposal:** It was felt that it would be difficult to obtain regulatory approval for manmade underwater waste rock disposal systems as there is no data to support their effectiveness.

   The pits at Matabbi will be used for flooded disposal of waste rock but there is concern over the impact of sulphide materials in the pit walls.

   Sulphide material in the pit walls above the waterline at the Sherman property will be a concern.

   Many open pit operations in Ontario are glory holes and can therefore not be used for waste disposal or be flooded until associated underground mining operations have ceased.

3. **Use as Mine Backfill:** This is common practice in Ontario but is dependent on mining method plus the availability of waste rock in association with an underground operation. This combination is found that Noranda's Geco and Matabbi operations, as well as at several of the Inco mines.

   It was suggested that the mining research group of Noranda Research be contacted for information on the criteria for using sulphide material as mine backfill.

4. **Sealing Techniques:** It was agreed that soil covers are useful in reducing the volume of water throughput and therefore transport of contaminants. However, the longevity of most forms of cover and particularly synthetic materials was questioned.

   In most areas of northern Ontario, the availability of soil is a problem.

5. **Bactericides:** John Hawley reported that potassium permanganate was used on a trial basis on sulphide tailings in the Elliot Lake area but was effective for a period of only about 3 weeks and had adverse side effects relative to the quality of runoff.

   SLS is regarded as a short-term control measure, providing in the order of 6 months benefit at significant cost.

   The possibility of genetic approaches to controlling Thiobacillus ferrooxidans was discussed but its ubiquitous nature means that any effective control measures would pose a significant environmental threat in themselves.

6. **Anaerobic Disposal:** A two foot layer of muskeg was used to cover a 4 acre dump at the Sherman property but its long-term effects are questionable. The use of sewage sludge was questioned due to undesirable side effects from organics such as benzene etc.

7. **Milling:** In Ontario, many waste rock piles are low-grade ore and the possibility of processing these through the mill represents an option in some situations.

Ranking of Research Requirements:

The development of reliable, predictive techniques was felt to be the priority research requirement. John Hawley reported that the Ministry of Environment has abandoned the B.C. test as unreliable. The Shebandowan Mine was developed on the basis that it would be an acid producer but has not proved to be so.

Potential Research:

The Kam Kotia Site reclamation will provide useful input to the RATS Program but primarily with respect to the reclamation of sulphide tailings. The acid waste rock aspects of this property are regarded as a minor issue.

The Sherman site provides an opportunity to investigate alternative waste rock management methods and is of particular interest as the rock is extremely reactive, yet relatively simple from a geochemical standpoint.

Item 5:

The following actions were agreed:

- Pat Bolger will provide estimated Inco tonnages.
- John Hawley will provide Ministry of Environment listing of mines after April 3.
- Bob Garrett will provide information on the evaluation of reclamation alternatives for Sherman Mine.
- A.V. Bell will contact Bob Michelutti for information on Falcolnbridge properties.

Summary:

John Hawley advised that acid waste rock management is not seen as a priority issue in Ontario, particularly with respect to uranium and acid generating mine tailings.

There was no other business and the meeting adjourned at 11:45 a.m.

cc: All present
Mr. Roy John, CANMET

NOLAN, DAVIS & ASSOCIATES

ACID WASTE ROCK MANAGEMENT STUDY

Place: Complex Scientifique
2700 Rue Einstein
Ste. Foy, Quebec

February 12, 1987
9:00 a.m.

Present: A.V. Bell; Nolan, Davis & Associates
Richard Siwik; Centre de Recherche Noranda
Guy Desmarais; Groupe Roche Inc. Pour Mines Sullivan Inc.
L. Jacques Moulin; Noranda Inc. - Horne
Guy Pelletier; Noranda Inc. - Point Claire
Jean-Guy Dionne; Service de Technologie Miniere
Andre Ouellet; Service Developpement Miniere
Claude Gignac; Environnement - Quebec
Mario Daigle; Environnement - Quebec
Denis Cote; Chef de Service - Service de Technologie Miniere
Jean Roberge; A.M.M.Q.

AGENDA

1. Introductions
2. Project Outline and Perspective (A.V. Bell)
3. Status of any recent legislation or policies in province relevant to waste rock
4. Study Information Requirements - Review and Discussion as per attached sheet
5. Agreed action
6. Any other matters

MEETING NOTES

A.V. Bell reviewed Items 1 and 2 on the Agenda.

Item 3:

The Quebec Ministry of Energy and Resources requires that a reclamation plan be submitted as part of an application for a mining permit. The minister of the environment also authorizes the site and monitors effluent quality etc. The Hazardous Waste Act does not officially define acid waste rock as a hazardous waste but the Act is used to address contaminated leachate from such waste. The A.M.M.Q. is requesting that MER be made responsible for the environmental aspects in permitting of all sites, including abandoned properties.

Claude Gignac provided a listing of questions to be answered as part of the environmental permitting process. These include definition of the acid-generation potential of potential waste material.

Item 4:

Denis Cote tabled the following material:

- list of exploration and abandoned mine properties in Quebec
- a report on Quebec metal mines and the environment. prepared in 1974
- preliminary inventory of mining waste with acid-generating potential (see attached)

The nine properties listed on Item 3 were reviewed as follows:

1. **Mines Gaspe** - the acid-generating material is the residue from a leach operation and is of relatively small tonnage. The mine is currently in operation and leachate from the pile is collected and treated.

2. **Weedon** - acid waste rock is widely distributed over the site and has been used for haul roads and general infrastructure. The property is abandoned. No data exists and no work is currently planned for the area.

3. **Solbec Cupra** - This is an abandoned property at which the sulphide waste rock has been stored separately. A waste pile containing 30.000 tonnes was covered with 20 cm of soil in 1978-79. This was not vegetated and erosion has occurred on the steep side slopes. There has been no monitoring of the effectiveness of the cover but the site may ofeer an opportunity to check its effect.

   Seepage from the flooded mine workings is acid and is impacting on local streams.

4. **Doyon** - This is an operating mine. The waste rock is confined to two piles, both of which are still active. The mine has experimented with bactericides on small areas and will work on a larger area this year.

   The wastes showed no sign of acid-generation for several years but suddenly turned acid. The mine constructed two ponds in which the leachate is treated.

5. **East-Sullivan** - This property has reverted to the government and is legally the responsibility of MER but the Ministry of Environment is responsible for its reclamation. The site consists of 120 acres of mixed tailings and waste rock. There is no separate rock pile. Waste rock was used for the starter dams of the tailings area, haul roads, etc.

   The government is considering applying wood chips and sewage sludge as a cover to the area and is reviewing the possibility of undertaking this work as a research project under the RATS Program.

6. **Manitou-Barvue** - This mine is closed but the mill on site is still in operation. Waste rock and tailings are intermixed and acid rock has been used for dams, roads, etc. and is therefore quite widespread.

   The mine has flooded and is generating acid seepage. No treatment has been considered. Mill effluent which is basic was pumped into the mine after closure but it has since reverted to an acid condition.

7. **Poirier** - Waste rock is widely spread over the property and has been used for general construction. There is a possibility of the mine reopening but no specific plans for dealing with the waste rock situation at this time.

8. **Lac Watson** - This is an active, underground property but contains seven old disposal sites, most of which are tailings.

9. **Normetal** - This an abandoned property which underwent an extensive reclamation program in 1981-86, in which all wastes were covered with sand and revegetated to conditions approved by Ministry of Environment. The work was undertaken by Noranda - Horne on behalf of Kerr Addison. There was no specific waste rock pile involved.

Summary:

Acid generating waste rock is not regarded as a major issue within Quebec since at the majority of acid-generating properties, the waste rock and tailings are intermixed. The priority is therefore more directed towards tailings reclamation.

Management Strategies:

Alternate management strategies for waste rock were discussed as follows:

1. **In-situ Neutralization** - There is no experience of this option in Quebec but it was felt to provide potential for existing mines with active waste rock piles under construction.

2. **Underwater Disposals/Flooding** - There are a number of examples of tailings disposal underwater in Quebec, including Copper Rand, Northgate, and Camchib, but little data on their acid-generation characteristics are available.

   Richard Siwik mentioned a reference titled "Marine Disposal of Tailings" by Ellis.

3. **Backfill Underground** - Noranda has used crushed slag for backfill at the Horne Mine. There were no other examples or comment on this approach.

4. **Sealing Techniques** - Work at the Selbaie Mine was outlined by Guy Desmarais and a copy of his company's report on the property provided.

   Noranda has used alkaline tailings to cover previously deposited acid tailings at five sites and has found that this has significantly reduced acid-generation. It was felt that covering waste rock piles with alkaline tailings would be very beneficial if such tailings were available. Obviously the solution is extremely site specific.

5. **Bactericides** - The experimental work at the Doyon Mine should provide useful information.

   Noranda Research is currently undertaking laboratory experiments relative to the Brunswick No. 6 property and will apply this in the field this spring.

   It was suggested that consideration be given to genetic engineering as a possible means of influencing the bacterial aspects of acid-generation.

6. **Anaerobic Disposal** - Establishing wet lands on waste rock areas was discussed but difficulties normally associated with the physical/topographical aspects of waste rock disposal areas were recognized as a major impediment.

   The use of sewage sludge on the East-Sullivan tailings may have some application to waste rock.

7. **Ranking of Research Requirements** - Quebec does not have any large waste rock piles but has many situations where acid waste rock is spread over large areas and inter-mixed with tailings. It was felt that these circumstances lended themselves to the use of bactericides, although this has not been recognized as a long-term solution.

The ability to categorize waste piles and understand the hydrogeology of specific piles was emphasized.

It was agreed that the RATS Program should develop as many options for dealing with waste rock as possible as it is unlikely that any single solution will apply to all situations.

The ability to cover and seal large areas is particularly important to the Quebec situation.

The Selbaie, Solbec, and Doyon sites appear to offer the greatest potential for acid waste rock research in Quebec. The appliction of an organic cover to the East-Sullivan tailings may also hae potential with respect to waste rock management.

Item 5:

No further action was identified.

Item 6:

No other business. Meeting adjourned at 12:20 p.m.

cc: To all present
R. John, CANMET

INVENTAIRE PRÉLIMINAIRE DES STÉRILES À POTENTIEL ACIDES (février 1987)

N° DOS. GERLED	NOM DE LA MINE	PROPRIÉTAIRE	LOCALISATION	PÉRIODE D'EXPLOITATION	% DE SULFURES MINERAI	UTILISATION DES STÉRILES	REMARQUES
01-03	Mines Gaspé (Cu)	Produits forestier McLaren Inc.	Murdochville				Haldes de roches sulfureuses
05-19	Weedon (Cu,Zn)	Municip. de Fontainebleau	Estrie	1910-1973 (intermittent)	5%	Régalage, infrastructure	Aucune halde - quelques monticules. Le minerai était extrait d'un gisement de sulfures massifs.
05-22	Solbec Cupra (Cu,Zn)	Mines Sullivan et Gouv.	Estrie	1962-1977	30%-40%	Régalage Digue	Solbec - roches stériles aux abords de la mine et recouverts de 20 cm de terre. Le gisement de sulfures massifs.
08-26	Doyon (Au)	Minerai-Lac	Cadillac (Abitibi)	1979-	---	----	Deux (2) Haldes de stériles Chaulage à l'effluent
08-48	East-Sullivan	Gouvernement	Val-d'Or	1949-1966	---	----	
08-52	Manitou-Barvue	Société Louvem	Val-d'Or	1942-1978 1982	15%	Régalage	12% à 20% de pyrite dans la roche stérile
08-63	Poirier (Cu,Zn)	Exploration minière Solbec	CM 516 bloc 7 Canton Joutel	1966-1975	33%	Régalage, infrastructure	Le minerai était extrait d'un gisement de sulfures massifs. Les roches stériles ont servi de remblai pour les galeries souterraines - aucune halde.
08-66	Lac Watson	Noranda, division Matagami	Matagami	1963-	35%-55%	Terrassement	en 1977, 96 150 tonnes de stériles produits 20% à 40% de pyrite dans le résidus
08-68	Normétal	Kerr Addison	Normétal	1937-1975	55%-60%	----	Pyrite 35% à 40% dans le minerai

NOLAN, DAVIS & ASSOCIATES

ACID WASTE ROCK MANAGEMENT STUDY

Place: Centenial Building   February 4, 1987
Fredericton, New Brunswick   9:00 a.m.

Present: A.V. Bell; Nolan, Davis & Associates
George Greer; N.B. Dept. of Natural Resources and Energy
Vaclav Kresta; N.B. Dept. of Municipal Affairs and Environment
Cathy MacLaggan; N.B. Dept. of Municipal Affairs and Environment
Hennie Veldhuizen; Noranda Inc.
J.R. Schnarr; Brunswick Mining and Smelting Corp. Ltd.
John Martin; Brunswick Mining and Smelting Corp. Ltd.
Leonard Surges, Brunswick Mining and Smelting Corp. Ltd.

AGENDA

1. Introductions
2. Project Outline and Perspective (A.V. Bell)
3. Status of any recent legislation or policies in province relevant to waste rock
4. Study Information Requirements - Review and Discussion as per attached sheet
5. Agreed action
6. Any other matters

MEETING NOTES

A.V. Bell reviewed Items 1 and 2 on the Agenda.

Item 3:

Mr. V. Kresta advised that the only legislative requirement in New Brunswick are those of the Mining Act. Internally, there is a policy that mines must develop a walk-away plan or commit to treatment inperpetuity. Walk-away plans must reduce discharge levels to those defined as "trivial".

Item 4:

Acid waste rock exists at the following properties in New Brunswick: Brunswick Mining and Smelting No. 6, Heath Steele Mines, Caribou New Brunswick Mines, Key Anacon, Wedge, Northumberland, and N.B. Coal. Each of these properties were reviewed as follows:

Brunswick No. 6:

- There are four waste piles:

  1. West pile, basically removed, used as backfill. Average 15 percent pyrite. Some concerns over hot spots in backfill.
  2. North pile, 1.8 million tonnes, relatively low acid-generation but some hot spots.
  3. East pile, .75 million tonnes, reletively low acid-generation.
  4. Pyrite pile, .5 million tonnes, 25 percent sulphides. Currently being backfilled into pit. 0.3 million tonnes still on surface.

- Cost of moving pyrite into pit is approximately $1 per tonne, but a cheaper option than long-term treatment. Incentive to do this now while Brunswick maintains a truck fleet. Far more expensive if contractor has to be hired.

- Proposing to do some experimental work with S.L.S. Will make a pile, apply S.L.S., and measure results. Need to define hydrogeological conditions.

- Brunswick No. 6, like most sites, has very poor definition of baseline conditions.

- North pile will be covered and sealed. West pile has been sucessfully reclaimed. East pile will either be covered and sealed or moved to the pit. Use of waste carbonate sludge as a cover (reject product from local pulp and paper mill) was attempted but benefits are unknown.

- Consideration has been given to using organic materials to create anaerobic conditions in waste piles. Sludge was mixed with an acid producing concentrate pile at Dalhousie. EPS has data.

Heath Steele Mine:

- Brunswick will provide plan showing waste locations and tonnages. Currently 21 waste piles plus waste has been used in haul road and rail bed etc.

- Gossan pile below East Pit has been partially removed. Long-term data exists for the runoff from this pile and completing removal and monitoring might provide a useful field experiment.

- Sulphur content of waste piles currently unknown.

Caribou N.B. Mine:

- Majority of waste piles have been moved into the pit. Acid drainage from these goes underground the mine, where it is pumped as mine water and treated. Sludge goes in the tailings pond.

- Mine is expected to reopen, thus may provide good opportunities for experimentation.

- Previous operators tried to stem AMD inflow to mine with bulk heads and found that this was diverted into Forty Mile Brook, upstream. Bulk head was therefore removed.

- Can contact Neil Smith with Caribou for further details.

Key Anacon:

- This is an abandoned shaft on the Nepisiguit River and includes a small waste-pile. The site is derelict and its characteristics and impact are unknown.

Wedge Mine:

- On the Nepisiguit River. This site was reclaimed by Cominco and is now regarded as being in satisfactory condition. No visible effluent from site.

Northumberland Mine:

- Also known as Murray Brook. Operators are proposing to remove gossan cover and leach for gold and silver values in a five year operation. This would not touch the sulphide ore body beneath the gossan.
- There is some acid-generating potential from the gossan.

N.B. Coal:

- Cathy MacLaggan has an inventory of spoil piles and their acid-generating potential. Two thousand acres produce drainage with pH 4. Eleven thousand acres less than 4.5.
- There is a program of recontouring waste piles, backfilling high walls and revegetation.
- Need for predictive techniques stressed. Problem has related to the high permeability of the sandstones being mined, thus the problem is mainly one of high groundwater flow volumes.

Management Strategies:

Alternate management strategies for waste rock were discussed as follows:

Insitu Neutralization:

Calcium Carbonate test at Brunswick No. 6 was more just a cover but had little impact. Westmin succeeded in increasing pH in their waste pile by injecting treatment sludge but sludge flushed through pile.

Underwater Disposal/Flooding:

Brunswick No. 6 is a prime example in New Brunswick. Equity Silver, Island Copper are examples out West. Long-term disposal in land-based, man-made flooded systems may give concern over long-term stability.

Backfill Underground:

Key parameters include quality (friability) of backfill, sulphide content (15 percent maximum), need to pump and treat acid drainage from underground. Use of stainless steel pipes and pumps is a major disincentive to backfilling. Brunswick will not even use sulphide material generated underground for these reasons.

Sealing Techniques:

Interest in Equity Silver test plots. Agreed that air elimination is the key factor.

Bactericides:

Work proposed at Brunswick No. 6 will provide useful data. Difficulty with scale up from lab tests. Difficulting in achieving total wetted surface in the case of waste rock relative to tailings.

Ranking of Research Requirements:

It was agreed by those present that the following represented a ranking of waste rock research requirements.

1. Determination of background conditions prior to undertaking acid-generation abatement tests
2. Definition of cost-effective priorities at a given site
3. Prediction techniques
4. Sealing methods
5. Anaerobic disposal conditions

It was agreed that the Heath Steele site provided many opportunities for applied research, particularly in view of the fact that monitoring data is available for many years, including metal balances for several points around the site.

Item 5:

- Leonard Surges will provide A.V. Bell with plans of the Heath Steele property, and also data on proposed bactericide tests at Brunswick No. 6.

Item 6:

- No other business. Meeting adjourned 11:40 a.m.

cc: All present
    R. John - CANMET

NOLAN, DAVIS & ASSOCIATES

ACID WASTE ROCK MANAGEMENT AT CANADIAN MINES

Information Requirements for each Province

1. Inventory of acid waste rock situations in Province:

   - location/name of property/type of mine
   - how long has acid waste rock been stored?
   - characteristics of waste rock, if available
   - approximate tonnage in place and rate of accumulation
   - methods of control implemented, tried, or considered
   - environmental implications
   - economic implications

2. Any data or available information on the following alternative management strategies for waste rock:

   - in-situ neutralization
   - underwater disposal/flooding
   - use as mine backfill
   - sealing techniques (for both air and water)
   - use of bacteriacides and other inhibitors
   - creation of anaerobic disposal conditions
   - long-term acid drainage control

3. Listing of research considered necessary to address acid waste rock problems in province.

4. Any sites lending themselves to applied research trials.

5. Priority of acid waste rock in province relative to:

   a) other environmental problems
   b) acid generating tailings

NOLAN, DAVIS & ASSOCIATES

ACID WASTE ROCK MANAGEMENT STUDY

INTERIM REVIEW WITH CANMET AND ENVIRONMENT CANADA

Meeting Notes

Place: 555 Booth Street, Ottawa
Date: April 28, 1987
9:30 a.m.

Present: A.V. Bell - Nolan, Davis & Associates
Roy John - CANMET
Mike Campbell - CANMET
John Ritcey - CANMET
Giller Tremblay - CANMET
Bill Blakeman - Environment Canada
Jim Scott - Environment Canada

- AVB distributed information package consisting of final report Table of Contents, Inventory of AWR in Canada, Summary of State-of-Art, and listing of AWR research requirements. Meeting consisted of reviewing this material. Key comments as follows:
- Were old base-metal properties in Nova Scotia considered, specifically Gays River and Stirling Mine? These were not acid producing.
- Fisheries and Oceans in Winnipeg is doing some excellent work on the acidification of bogs and lake sediment stability. Contact Ray Hesslein (949-5256).
- Dr. Suzeki of U of M contracted under MDA to review role of bacteria in sulphate leaching. R. McCready will provide AVB with project description sheets for this and other CANMET leaching studies.
- Crushing of waste rock for disposal in tailings was thought to be preferable to milling (Item 5.2.4(O)).
- G. Ritcey suggested that treatment methods based on chemical exchange barriers and possibly reverse osmosis should be included in Item 5.2.4(O).
- General concensus that the balance of the report and findings as presented were `on track'.
- Meeting adjourned at 11:30 a.m.
- A.V. Bell and R. John reviewed text in greater detail. RJ provided data etc., on air diffusivity, etc.

cc: All present

APPENDIX B

RATS PROJECT SHEET

Project Number: 1.1
Original Author: R.E. Michelutti
R. Siwik

Original Date: 86/09/29
1st Revision: 86/11/01

PROJECT TITLE

Evaluation of solid covers as oxygen and water barriers on sulphide tailings and the effect of capillary barriers on upward salt migration.

Objective

To define and evaluate barriers techniques to minimize the movement of oxygen and water into sulphide tailings. This would include synthetic and natural barriers as well as investigating capillary breaks.

Resources

Contract $ Coming year $ 130 K Total $ 1,250 K

Category	Description	$	Date
	State of the Art, Laboratory and Field Studies	130 K	1987-88
	Pilot and Field Trials	300 K	1988-89
	Full-scale trials	300 K	1989-90
	Full-scale trials	245 K	1990-91

Background:

The mechanisms for pyrite oxidation and resultant acid production had been well established. Review of this data suggests that transport processes (diffusion of oxygen) are far more significant than the pyrite oxidation rate. Thus, new research should be focused on obtaining better estimates of the diffusion co-efficient of oxygen rather than measurement of pyrite oxidation rate and tailings chemistry. Similarly work needs to be undertaken to establish which materials provide the greatest control over oxygen and water diffusion.

This project is seen as one of the major functions of the RATS program. The effort will be direct towards demonstrating the effectiveness of engineered covers for control of acid generation by minimizing the diffusion of oxygen and water through various covers. Surface reclamation may then be done by conventional techniques and provide integrity from errosion by surface run-off.

Summary:

1. Review the existing information. This as been done through a certain extent by individual TWG members. However it needs to be integrated and re-reviewed in a systematic fashion.

2. Undertake a laboratory investigation on saturated solid covers and potential capillary breaks.

3. Suficient data exist to develop an appropriate hypothesis. The need is to minimize oxygen and water infiltration.

4. Evaluate existing covers for their effect on acid production. Measure oxygen diffusion co-efficence and hydrolic conductivity on these materials select the most promising candidates for full scale trials.

5. Perform field trials of selected technologies..

6. Document the most appropriate techniques for full-scale use by industry.

Note: Some research work had already begun before the RATS program came into being. Therefore, it is not possible to follow the accepted logical sequence. The above plan should enable the existing work to be integrated in such a fashion that it contributes to the ultimate goal of this program.

Outputs:

Sets of data defining the effectiveness of various cover techniques, leading to a final documents of recommended practices appropriate to acid generating tailings in Canadian climate conditions.

RATS PROJECT SHEET

Project Number: 2.1

Original Date: 86/09/29
1st Revision: 86/11/01

Authors: R.E. Michelutti
D.C. Cook

PROJECT TITLE:

The Use of Aqueous Covers to Prevent Oxidation.

Objective:

To maintain a water and/or water plus organic cover on acid generating tailings to reduce the oxidation of suphur bearing minerals.

Resources:

Coming year $ 80 K Total $ 490 K

Description	$	Date
Literature review, field investigations and trials	80 K	87-88
Field investigations and trials	60 K	88-89
Field trials	110 K	89-90
Field trials	110 K	90-91
Field trials	130 K	91-92

Background: A great deal of work exists to show that sulphur oxidation in tailings is greatly reduced when submerged. This is due to the reduction in oxygen diffusion rate caused by the water barrier.

There are two potential technologies that can be used to achieve a water cover. The first is to flood the tailings, by building an impervious dam to maintain an adequate water level, or by placing the tailings in a deep lake during the operation of the mill. It is not yet clear what minimum depth of water is needed and what contribution to contaminate migration occurs at the margins. Placing the tailings behind engineered dams also raises questions of long term dam stability.

An alternative method to maintaining a saturated, and therefore oxygen impervious layer is to develop a self sustaining wetland on the tailings surface.

This has already been shown to provide the desired deduction in oxidation rate. Many questions remain on how to develop the wetlands, what are the most effective form of wetlands, and what is the long term viability of these structures.

/...2

Summary:

1. Review of existing information, again using the TWG members as a basic resource. Comprehensive evaluation, probably with the use of an external resource (Agriculture Canada scientist).
2. Evaluate existing field trials.
3. Continue work on existing experimental field trials.
4. Develop alternatives based on the results of the current field trials and the review of existing data. Implement these in locations that will show the adaptability of this technique.
5. Document the results of the work and make recommendations on the viability of the technique, and if successful a technology manual to describe appropriate application techniques.

Output:

Definition of the usefulness of the technique and, if appropriate, a technology manual.

RATS PROJECT SHEET

Project Number: 3.1 Original Date: 86/10/10

Original Authors: D.C. Cook

PROJECT TITLE: The Investigation of Hardpan Formation

Objective:

To determine the sequence of natural influences that result in the formation of hardpan in sulphide tailings.

Resources:

Coming year $ 200 K Total $ 600 K

Description	$	Date
Sample existing hardpan for detailed examination.	100 K	87-88
Laboratory trials and simulation	100 K	88-89
Laboratory trials and simulation	100 K	89-90
Field trials	300 K	91-92

Background:

A hard, impervious (to oxygen and water) layer has developed naturally in some high sulphur tailings. Below this layer there is little evidence of oxidation. There is little understanding of how hardpan is formed, what its properties are, and how to encourage its development. If hardpan is effective control of oxidation and contaminant migration then the creation of synthetic hardpan could solve many problems. This is particularly true in northern areas where suitable cover materials are lacking and there is a short growing season.

This project will study the natural hardpan from various sites to elucidate its chemical structure. Attempts will then be made, in the laboratory to encourage the growth of this cement-like material. If a continuous competent and permanent hardpan can be developed a passive abandonment of sulphide tailings is possible. From the methods developed under laboratory conditions the most attractive will be chosen to be tried in the field. The rate, depth and effect of hardpan formation will be monitored at selected site or sites.

Summary:

Obtain field samples and establish their chemical composition.

Conduct laboratory experiments to ascertain the chemical formation of hardpan.

Develop a hypothesis on hardpan formation that can be used in the field.

Run field trials with selected hardpan formation techniques.

Output progress reports evaluating natural and artificial hardpan as a method for the abondonment of reactive tailings. Establishing criteria for hardpan creation and maintainance.

RATS PROJECT SHEET

Project Number: 4.1

Authors: R.E. Michelutte

Original Date: 86/09/29
1st Revision: 86/11/01

PROJECT TITLE: Use of Wetlands as a Downstream Passive Treatment System for Acidic Tailings Seepage.

Objective: To develop a downstream wetlands that will remove heavy metals from acidic tailings seepage.

Resources: Coming year $ 110 K Total $ 250 K

Description	$	Date
Literature review and field trials	110 K	87-88
Field trials	80 K	87-88
Field trials	60 K	88-89

Background:

It has long been known that highly organic wetland material takes up heavy metals thereby purifying any water that flows through them. So far these efforts have used existing wetlands that have primarily been fortuitous in their location. There has been little systematic effort to encourage the formation of wetlands, to see which wetland types are the most effective and to ascertain the longevity of such wetland areas.

Summary:

1. Review the existing literature.
2. Review the work done so far under the RATS Program.
3. Measure the efficiency and saturation limits for complex metals in typical wetlands material.
4. Determine the possible re-release in the long term with changing conditions or plant mortality.
5. Determine the long term viability of the wetlands relative to the potential timeframe for contaminant seepage problems.
6. Select suitable wetland communities for field trial experiments.

7. Evaluate the results of the experiments and report on the effectiveness of wetlands as a treatment system.

Outputs:

The final study should indicate the practicality i.e., the cost effectiveness of using downstream wetlands for the treatment of acidic metal laden seepages. The ultimate design must allow for maintainance free abandonment.

RATS PROJECT SHEET

Project Number: 5.1

Authors: K.G. Wheeland

Date: 86/09/29

1st Revision: 86/11/01

PROJECT TITLE: Techniques for Downstream Passive Treatment of Tailings Seepage (Excluding Wetlands)

Objective:

To define, evaluate and implement, as warranted, techniques for the passive treatment of tailings seepage (excluding wetlands).

Resources: Coming year $ 40 K Total $ 400 K

Description	$	Date
Literature review	40 K	87-88
Pilot field trials	150 K	88-89
Full-scale trials	110 K	89-90
Full-scale trials	100 K	90-91

Background:

It is likely that post-closure seepage from many existing tailings areas will require treatment for a considerable period of time. This project will examine the prospect of chemical or physical treatment in a passive (or minimal operation) mode.

Summary:

1. A brief state-of-the-art review will be conducted re passive systems including neutralization, physical sorption, binding, etc. The emphasis will be on low cost maintainance systems.

2. A hypothesis will be developed based on now exisitng chemical knowledge for inplant trial. It is not expected that laboratory trials will be required as a prerequisite field trials.

3. Large scale trials will be conducted on the best processes identified. It is assumed that the operating company will pay for the installation and maintainance and RATS will cover the cost of technical evaluation.

Outputs:

Progress reports will be made culminating in a manual of the successful method or methods.

RATS PROJECT SHEET

Project Number: 6.1 Original Date: 86/10/20

Authors: Bob Gardiner 1st Revision: 86/11/01

Project Title: Re-Vegetation of Reactive Acid Tailings.

Objective:

To define the role of vegetation in reactive acid tailings management through a state-of-the-art review of re-vegetation technology and and related information on the effect of vegetation and associated amendments.

Resources: Coming year $ 30 K Total $ 30 K

Background:

The role of vegetation in tailings management is generally limited to stabilizing the surface and improving the aesthetics. Land reclamation regulations in some provinces require re-establishment of a specific land use on a tailing disposal site. There is speculation that vegetation has an additional role in management of reactive acid tailings, namely, that of reducing or even preventing oxygen generation by minimizing water infiltration and oxygen diffusion. If vegetation fulfilled this potential ole, cost for environmental protection following abandonment of reactive acid tailings sites would be eliminated. However there is considerable experience to question these conclusions.

Revegetation experience on reactive acid tailings sites in Canada was originally reviewed in 1984 by Monenco. Factors influencing revegetation and the variable results of prevalent revegetation techniques were discussed. The impact of vegetation was not addressed.

The purpose of the proposed project is to provide a state-of-the-art review of revegetation technology. Any comments on the effects of vegetation will also be included.

Output:

Review report.

RATS PROJECT SHEET

Project Number: 7.1

Original Date:

Authors: C. Ferguson
E. Joe

PROJECT TITLE: State of the Art Review of Tailings Impoundment Practices.

Objective: Produce a review of currently available tailings disposal practices and costs (including surface treatment and seepage management schemes).

Resources:

Coming year $ 15

Total $ 50 K

Description	$	Date
Assemble Literature Derive Data	15 K	87-88
Contract Report	35 K	88-89

Background: A number of innovative tailing disposal systems have been brought into commercial operations in response to the recognized need to improve stability, and designed to reduce final abandonment problems and costs. No recent publication has served to collect and compare current technical advances made in tailing disposal practices. This proposed project would serve to eliminate this defficiency in the technical literature.

Summary: Raw data assembly is a relatively simple job but distilling the literature into a comprehensive, cohesive review will entail considerable artwork and technical writing.

Outputs: The final product, a published state-of-the-art manual reviewing currently available disposal systems for mine wastes would serve as a handbook to guide the selection of disposal techniques, seepage control and surface treatment practices developed to meet increasingly stringent regulatory demands.

RATS PROJECT SHEET

Project Number: 8.1
Author:

Date: 86/10/07
1st Revision: 86/11/01

Project Title: Review of NUTP Contracts.

Objective:

To review the work done by the NUTP to assess its relevance to the RATS program and produce summaries of the most useful information for the TWG.

Resources: Coming year $ 70 K   Total $ 70 K

Description	$	Date
Executive summaries collated into 8 categories.	10 K	Nov. 36
Reports sent to reviewers for review	40 K	Dec. 86
Summary reports written	20 K	May 87
Discussion of all reviews.		June 87

Background:

The NUTP has had over 100 contracts of which about 30-36 are useful to RATS. This material should be reviewed so that duplication does not occur.

Summary & Scope of Work:

1. The relevant contracts should be chosen (RDJ) and executive summaries collected for each reviewer (RDJ).
2. Volunteer reviewers should asses the value of the various reports available and request those that are most pertinent.
3. The reviewers will give a thorough review and produce a summary suitable for the technical working group.
4. The summaries produced by the reviewers will be formed into an informational text for all of the technical working group.

Outputs:

A concise review of the NUTP contracts.

RATS PROJECT SHEET

Project Number: 9.1 Original Date: 86/10/07

Author: R. John

Project Title: Overall Literature Review

Objective:

To collect and assess the existing data pertinent to the RATS Program.

Note; we felt the best way to handle this problem is that all members of the technical working group act as a collecting agency for pertinent information. CANMET staff will provide a secretariat role. Members of the group who find suitable information should send either a copy of the report article, etc. or a reference to the RATS-CANMET staff. The executive summaries or equivalent will be circulated on a regular basis to the TWG. Eventually all the references will be loaded into a computer by the technical information department of CANMET. Members of the TWG can request a full copy of the publication, except for large volume items such as books. The RATS-CANMET staff will maintain a reference library of all material submitted by the members.

RATS PROJECT SHEET

Project Number: 10.1	Date: 86/09/29
Author: K.G. Wheeland	1st Revision: 86/11/01

Project Title: Field Procedures Manual for Reactive Tailings Evaluations.

Objective:

To provide a consistent and technically valid basis for all field work conducted within the Reactive Acid Tailings, including newly developed methods.

Resources: Coming year $ 30 K Total $ 30 K

Description	$	Date
Preliminary definition of manual contents (adapted from NUTP manual)		Jan.-May 86
Preparation of draft contributions re "effects on environment" and "analytical methodoligies"		July 86
Preparation of other required draft sections		Dec. 86
Preparation of a comprehensive revised text by a contractor based on the guidelines above	30 K	Apr. 87

Background:

A field manual, similar to that prepared for the NUTP was identified by the TWG as being essential to ensure that all contractors conduct the fieldwork in a consistent and valid manner. As an initial step, R. John, K. Wheeland and R. Prairie reviewed the NUTP manual, identified major additions and modifications required, and drafted up some of the additional material required.

Summary:

1. A contractor will prepare a Field Manual for the RATS program based on the guidelines and draft additions provided.
2. There will be no work in subsequent years unless updates and additions are warranted. The outputs are a Field Manual by April 1987.

RATS PROJECT SHEET

Project Number: 11.1 Date: 86/09/29

Author: K.G. Wheeland

Project Title: Analytical Procedures Manual

Objective:

To provide a consistent and technically valid basis for all analytical work conducted within the Reactive Tailings Program.

Resources: Coming year $ 20 K Total $ 20 K

Description	$	Date
Outline the needs of analytical methods, reference samples of statistical methods.		Jan.-Aug. 36
Define scope and contents of the manual		Sep.-Dec. 86
Prepare and issue manual	20 K	Jan.-Apr. 87

Background:

A guide to analytical methodologies, quality assurance and interpretation was identified by the TWG as being an essential tool for all contractors. During discussions of the Field Manual, certain requirements for the Analytical Manual were specified by R. John, H. Steger, K. Wheeland and R. Prairie. Further definition, spearheaded by H. Steger is required before contracting out the manual preparation.

Summary:

A contractor will prepare an Analytical Manual suitable for the RATS program. Several contributors may be required re special analytical procedures. No work is expected in subsequent years unless updates and additions are warranted.

Outputs:

An Analytical Manual by April 1987.

RATS PROJECT SHEET

Project Number: 12.1
Date: 86/10/03

Author: C.W. Smith
1st Revision: 86/11/01

Project Title: Reactive Tailings Reference Materials

Objective:

To provide reference samples of Canadian source pyritic tailings solids, characterized for the content of important chemical components and available for methods testing and quality assurance applications for the RATS program, and potentially available to other analytical facilities via CANMET.

Resources: Coming year $ 40 K Total $ 40 K

Description	$	Date
Define sources	0	Jan. 87
Acquire suitable samples	3 K	Mar. 87
Standards preparation	3 K	May. 87
Interlaboratory measurement program	25 K	Sep. 87
Documentation and assesment	6 K	Jan. 88
Sample distribution		Jan. 88

Background:

It was recognized by the TWG that some form of analytical standards were required. The least expensive way to achieve this objective was for members with identified suitable tailings sources to supply CANMET with adequate quantities of materials. CANMET would then prepare this material as a reference standard and send samples to all the TWG participants. The TWG members would process these samples through their own labs and return the analytical results to CANMET for evaluation. The results from this round robin program would be published and members would be able to use the samples as reference materials in RATS related projects.

Summary:

A number of pyritic tailings reference materials will be prepared and characterized and subseqently made available.

Outputs:

One to two thousand 200 gram units of each material and associated documentation.

RATS PROJECT SHEET

Project Number: 13.1 Original Date: 86/10/29

Project Title: Evaluation and Monitoring of RATS Projects.

Objective:

Develop a evaluation and monitoring manual to be applied to RATS projects.

Resources: Coming year $ 20 K Total $ 2 0 K

Description	$	Date
Prepare an evaluation and monitoring manual	20 K	87-88
Apply the evaluation and monitoring techniques to RATS projects	50 K	90-91
Apply the evaluation and monitoring techniques to RATS projects	150 K	90-91
Apply the evaluation and monitoring techniques to RATS projects	50 K	91-92

Background:

It is vital to the success of the RATS program that the provincial and federal regulatory agencies understand the objectives and are prepared to evaluate the results of the project. Ultimately the licence for close-out will be issued by one of these regulatory agencies. It is essential that the TWG understand the evaluation and monitoring techniques that must be used and how these can be correlated with the government requirements.

Summary:

The first draft of an evaluation and monitoring manual will be prepared by the Ontario Provincial Government representative. This will be reviewed by the members of the technical working group, including other provincial government representatives. When this manual is finalized it will be printed and copies distributed to the TWG. When RATS field trials or full-scale trials are considered to be working satisfactorily these monitoring techniques will be applied to evaluate the success of the individual projects.

RATS PROJECT SHEET

Project Number: 14.1

Date: 86/10/07

Author: R.W. Holmes

1st Revision: 86/11/01

Project Title: Model Development

Objective:

To develop predictive methods for the long-term environmental effects from reactive acid tailings.

Resources: Coming year $ 155 K Total $ 335 K

Description	$	Date
Review by committee	20 K	Jan. 87
Review existing component models and revise as necessary	30 K	Feb. 87
Develop computer software for revised models	30 K	Apr. 87
Develop data for hypothetical reference site	20 K	Apr. 87
Run model on hypothetical reference site	35 K	May 87
Document results	20 K	Jul. 87
Part II-application to real site,collection of data and running model	200 K	88-89

Background:

The NUTP has produced a probabilistic system model to predict long-term environmental effects from uranium tailings. It describes the contaminant movement in tailings through the environment to humans. Its' intended use is to distinguish between the effectiveness of various potential disposal options. The model is flexible in that its modular framework allows for the application to non-uranium tailings.

If the development of a mathematical model is successful then it will require a practical demonstration at a real site. Data would need to be collected to characterize the site and development of site specific models. Some data would also be required for model calibration purposes.

Summary:

Review the existing NUTP component models for application to base metal tailings sites. Revise these accordingly and apply to a hypothetical site.

Develop site specific models and input data and calibrate against field data. Apply the calibrated model to a specific site for long-term predictions of various disposal options. This would require planning a field program to coincide with the modelling needs.

Output:

Models and corresponding computer program for predicting the long-term effect from acid generating tailings. Demonstrating the model at a specific tailings site.

RATS PROJECT SHEET

Project Number: 16.1 Date: 86/11/07

Author:

Project Title: Contingencies

Objective:

To allow for contingency funding in a research program now found.

Resources: Coming year $________ Total $________

Description	$	Date
	50.	87/88
	200.	88/89
	300.	89/90
	400.	90/91
	500.	91/92

Background:

In any research endeavour it is anticipated that the work will lead to new ideas. Most promising of these ideas should be followed up and will therefore require a funding. It is impossible at this date to speculate on what those ideas might be. However it is possible tc make a funding allowance for future years. Obviously the chance of a new idea emerging and the uncertainty in the amount of the funding required increases with time. This is reflected in the contingency funding levels proposed.

Summary:

Allowance has been made for contingency funding.

Outputs:

RATS SUMMAR. HEET

$ in 000,s

	calendar year	1987	1988	1989	1990	1991	1992
	fiscal year						
1.1	Barriers - dry	130	300	300	245		
2.1	Barriers - wet	80	60	110	110	130	
3.1	Barriers - hardpan	100	100	100	300		
4.1	Wetlands	110	80	60			
5.1	Passive treatment	40	150	110	100		
6.1	Vegetation	30					
7.1	State of the Art	15	30				
8.1	Review - NUTP	50	20				
9.1	Review - General						
10.1	Manual - Field	30					
11.1	Manual - Analytical	20					
12.1	Reference Materials	40					
13.1	Evaluation & Monitoring	20		50	150	50	
14.1	Modelling	155	200				
15.1	Chemical predictive	30	50				
	SUB-TOTAL	850	990	730	905	180	
16.1	Contingency	50	200	300	400	500	
	TOTAL	900	1190	1030	1305	680	
	OVERALL TOTAL					5,105	